REFRACTORY FACTS



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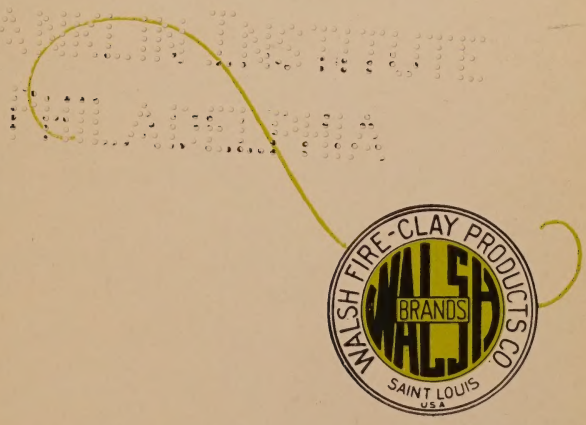
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A hand-book of essential information about Fire-Clay Products



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A FOREWORD

IN preparing this catalogue, we have been mindful of the need for some scientific facts concerning fire-clay products, which has been expressed to us many times by various users. Without attempting to compile an exhaustive treatise on the subject, we have endeavored to supply some data that would serve the convenience of the busy executive, and which would also encourage the juniors in the organizations to pursue their investigations of the subject further.

Grateful acknowledgment is made for help of various kinds to The Hinrichs Laboratories, St. Louis; The Mellon Institute of Industrial Research, Pittsburg, and to the authorities mentioned in various foot-notes appended to the text.

As a booklet such as this can be at the best only a bare outline of the subject, we will be pleased to have the opportunity to discuss practical questions with our readers, or to go more into detail regarding any portion of the following pages.

ROBERT A. B. WALSH,
President.

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St. Louis, U. S. A.

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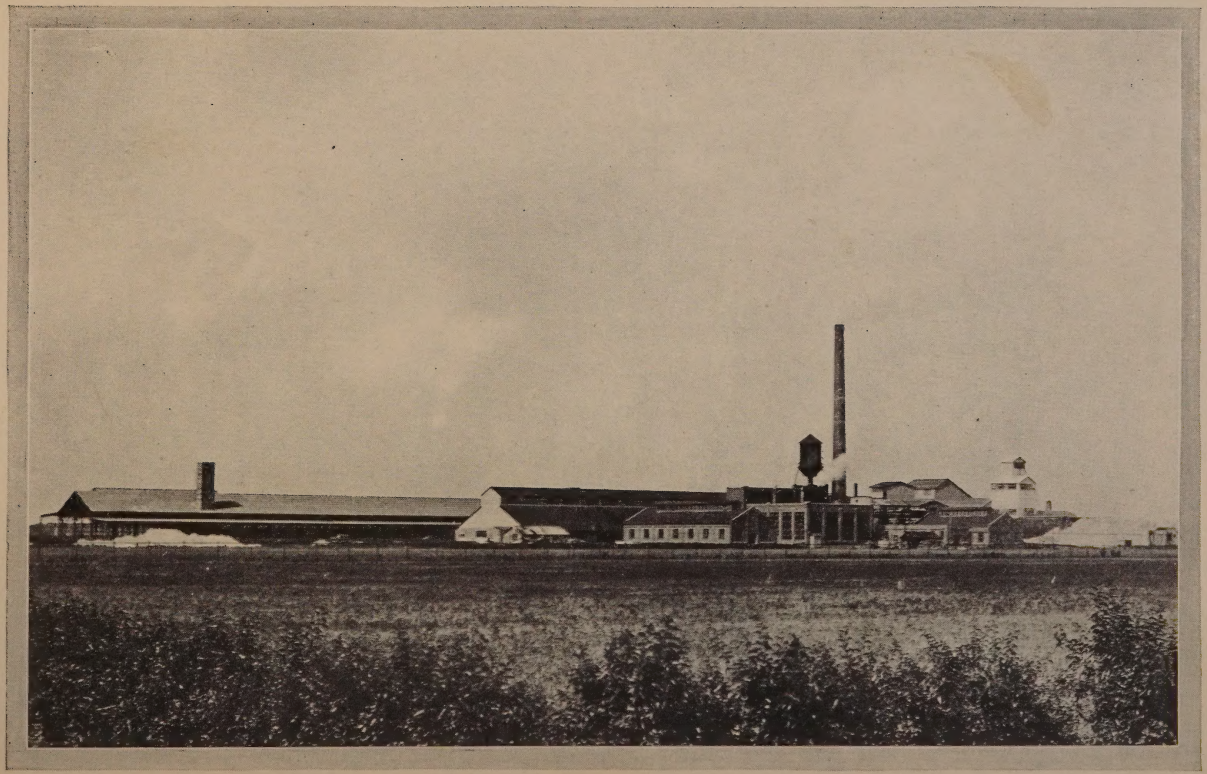


PLATE 1—View of the New Walsh Plant, Vandalia, Mo.

REFRACTORY FACTS

CHAPTER I

ABOUT OURSELVES

THE Walsh Fire Clay Products Company represents the development of a manufacturing ideal; it is the result of constant effort on the part of the Mississippi Glass Company to produce refractory material of the highest possible grade. From the year 1890 until 1915, what is now the Walsh organization was known to the trade as The Fire Clay Department of the Mississippi Glass Company.

Since the time, years before the period mentioned, when its glass-melting pots, furnace blocks and glass-house refractories were shipped from Pittsburg to the east bank of the Mississippi River and hauled by wagon to the glass works, the Mississippi Glass Company had made surveys and tests leading to the development of a more convenient source of supply of fire-clays of the outstanding quality necessary in the economical operation of glass melting furnaces. When there were found in Missouri, fire-clay areas of extraordinary quality, the Glass Company began to manufacture all the refractories, pots, blocks and fire-brick used in its own operations.

In glass furnace practice, it was observed that improvements in the quality of refractories, of a degree generally considered of slight importance, always yielded increased service that was beyond expectations. Thereafter every effort was directed toward the development of these so-called "slight" gains in quality.

Other glass manufacturers soon became aware of the high quality refractories made by the Mississippi Glass Company, and the company was called upon to serve them. These demands grew and in 1890 the Fire Clay Department was formally organized. The well-equipped clay manufacturing plant of Thomas Coffin & Company, Ltd., in St. Louis, was secured with its additional force of skilled operatives.

In 1900 a second refractories plant was acquired at Vandalia, Mo., which was eventually enlarged to a daily capacity of 50,000 brick.

In 1915, in order to identify the product more definitely, the Fire Clay Department was incorporated under the name, "Walsh Fire Clay Products Company." As the Mississippi Glass Company name had descended through successive generations, this severance, although only in form, was made with reluctance to conform to business expediency. The ownership and management remain unchanged.

In 1917 to meet the larger demands for "Walsh Brands," and to standardize the improvements that had been developed, construction of the new plant near St. Louis was started. That plant is briefly described and illustrated in this book.

"The Proper Material to Meet the Furnace Conditions," is the Walsh Slogan; "Better Refractories" continues to be the chief objective of the Walsh Organization—the ideal that means satisfaction to users of "Walsh" Brands.

Co-operation with the railroad freight traffic departments, on the part of the shipper, is always helpful to the consignee.

Definite information relative to freight movements is furnished, unnecessary delays in transit are prevented, the most advantageous routes are specified, rates are checked, not to mention other benefits provided by a well equipped Traffic Department.

The Traffic Manager of this Company is an official of seasoned experience in the railroad business. Every order passes through his office before it is sent to the factories for execution.

In such matters as handling claims for damages incurred in transit, tracing shipments, or any matters pertaining to shipping, customers are invited to avail themselves of the expert services of the Traffic Department.



PLATE 2—Power House—Coal Storage Yard—Walsh Plant.

CHAPTER II

Why Some Clays Are "Fire" Clays

CLAYS are the residue of feldspathic rocks that were distintegrated by ages of "Weathering," which is the convenient term used to describe the action of water, heat and cold. Granite is the most common feldspathic rock, but such formations exist in great variety and quantity. Granite is a mixture of feldspar, the predominating material, and quartz, with small proportions of mica and two or three other rocks whose characteristics and names it is not necessary to consider further.

Feldspars Feldspars are essentially silicates of alumina[1] combined with smaller quantities of potash, soda or lime. During the weathering action that has been at work for millions of years, these last-named substances have for the most part been dissolved and separated from the decomposed feldspar. This separation has left a clay material composed of di-oxide of silicon (SiO_2) or silica, in chemical combination with aluminum oxide, (Al_2O^3) or alumina, and water, together with varying proportions of uncombined or "free" silica (sand), potassium oxide, magnesium oxide, iron (ferric) oxide, and oxide of titanium.

Composition Of Fire-Clay Clays vary with the character of the rocks from which they were derived; chemically pure clays do not occur in Nature. Theoretically, pure fire-clay is the chemical

[1] See page 21

combination of silica, alumina and water according to the formula[1] $Al_2O_3 . 2SiO_2. 2H_2O$. Proportions by weight according to this formula are: alumina 39.45%; silica 46.64%; water 13.91%. This substance possesses unusual heat-resisting qualities. Consequently when most of the deleterious elements have been washed out during the disintegration of the original feldspars and the residue conforms approximately to hydrous silicate of alumina, you have a clay that resists heat to such an uncommon degree that it is called "Fire-clay."

Plasticity and Refractoriness Most clays become more or less plastic (soft and paste-like) when ground in water. In the United States are large deposits of hard, non-plastic clays which break with a sharp conchoidal fracture; these are termed "Flint" clays. Other clays, called "Semi-flints," that seem to share equally the characteristics of both the plastics and the flint clays are not uncommon. There is no relationship between the hardness and the refractoriness of fire-clays.[2]

Analysis The causes of plasticity in clays are not fully understood by chemists or physicists. In fact, the authorities in the technology of clays agree that chemical analysis alone is not a safe guide for determining either the degree of plasticity or refractoriness. Synthetic clays, compounded in the laboratory for purposes of comparative tests, do not behave like natural clays—actual results are frequently the reverse of what had been predicted upon

[1] See page 22

[2] The fire-clay properties of this Company comprise an extensive acreage in several districts. They were acquired, for the most part, by the parent company, The Mississippi Glass Company. Flint, semi-flint and highly refractory plastic clays underlie these lands in abundance.

the basis of chemical analyses. For these reasons the best authorities of the present day base their conclusions concerning clay products almost exclusively upon physical tests, recognizing the fact, however, that the influence of some of the constituent elements of fire-clays has a more pronounced effect upon their refractoriness than others. Iron oxide (Fe_2O_3) and oxide of titanium (TiO_2), both of which are nearly always present in fire-clays, are comparatively inert and harmless within ordinary limits. On the other hand, the oxides of potassium and sodium, commonly termed the alkalies, and magnesium oxide are "violent" in their action; their presence in excess is regarded as a danger signal to the manufacturer.[1]

Spalling Because of their physical properties, high-grade fire-clays, to use the commercial term current with those who work with clay products, are more useful generally than other refractories. Silica expands at working temperatures; the better grade of clay refractories, however, are comparatively neutral as to expansion and contraction.[2] Since the variation of heat conditions tends to break most brick to pieces in a short time, it is important to select high-grade neutral products. Such materials resist repeated changes of temperature with less injury than that imposed upon other classes of refractories. The action of a brick, chipping off or going to pieces from

[1] The Walsh fire-clay deposits are notably free from excessive alkali. The following analysis of a Walsh XX brick by the Mellon Institute of Industrial Research (Pittsburgh) is typical:

Silica	53.12	Lime	.64
Alumina	43.30	Magnesia	.46
Ferric Oxide	2.48	Alkalies	.15

[2] Prof. D. A. Moulton, Iowa State College, Ames, Iowa, tested 3 samples of Walsh XX brand of brick; at "cone 33 down" the specimen showing an average expansion of 1.03%.

the effect of repeated expansion and contraction is called "Spalling."

Clay is classed as a granular substance, but the true fire-clay, free of foreign materials, is composed of such exceedingly small particles that a specimen mixed with twice its weight of water, passes through a screen of 250 mesh fineness, which contains 62,500 openings per square inch of screen surface.(1) Plastic clays for certain classes of materials are "Washed" by dissolving them in pure water. The solution, with the genuine clay held in suspension, is drawn off and evaporated or filtered through filter-presses. This process removes a considerable percentage of native impurities.

Mining Methods The fire-clay deposits of Missouri are mined by various methods; open-pit mining with steam shovels is practicable in some localities; drift mines prevail in other sections, and some large areas are exploited by means of shaft mines. The deposits vary to a considerable degree in thickness, area and quality.

There are in great abundance so-called "fire-clays" suitable for the manufacture of a large variety of products, but some authorities question the correctness of applying the term "refractory" to all such clays.[2] Users of refractory materials are rapidly becoming more discriminative, following the lead of a few large consumers who have made extensive investigations and given special attention to the subject.

[1] Alfred B. Searles, "Clays."

[2] Bleininger & Brown—Bureau of Standards Tech. Paper No. 7.

CHAPTER III

A Short Outline of Chemistry

THOSE readers who had the opportunity to study Chemistry during their school days have probably felt the need of reviewing the subject when reading technical articles. Those who have not studied the subject at all will derive more benefit from their study of refractories and their uses, if they have even the slight acquaintance with the principles of Chemistry that can be offered in this brief outline. Our purpose is to promote a better understanding of clay manufacturing and of the uses of refractories.

Matter All substance, or matter, is first classified under the headings Solids, Liquids and Gases. Some substances under different conditions, exist in each of these three states. Water for instance is a solid at the temperatures 32 degrees Fahrenheit or lower, a liquid between 32 and 212 degrees, and a gas at temperatures above 212. Many other substances behave in a similar fashion, although at varying freezing and boiling points; mercury freezes at 38 degrees below zero Fahrenheit; iron boils at 4442 degrees Fahrenheit, to cite only two examples.

Matter, or Substance, which are used interchangeably in this outline, could not be understood if we should accept, as final, the evidence of our senses. That which may appear to be a dead, inert mass of material, whether a stone, a log of wood, a pool of water, or a body of gas, is in fact only the outward appearance presented by innumerable individual moving particles called molecules (pronounced molly-kiules). Molecules are too small to be visible even by the aid of the most powerful microscopes, but the experience of thousands of able and learned

scientists is proof that the theory of molecules is as practical to the world's work as meat and potatoes.

All substance, then, is made up of countless invisible particles which are in a state of motion or vibration. If the molecules are very close to each other the substance is correspondingly dense and hard; if the distance between them is relatively great, the substance is light, liquid, or gaseous. The study of the activity and condition of molecules is called "Physics." Electricity, Heat, Energy, Motion, Expansion and Contraction are some of the common classifications of that science.

Molecules do not, however, constitute the final subdivision of matter. A molecule is made up of smaller particles called "Atoms." Upon theories of the action of atoms, the science of Chemistry is based.

Substances built up of but one kind of atom are called "Elements;" those built up of molecules—two or more kinds of atoms—are designated "Compounds." Gold, for example, silver, iron, oxygen, etc., are elements. Sulphuric acid, on the other hand, when analyzed is found to consist of hydrogen, oxygen and sulphur, chemically combined; it then, is a compound. There are 83 elements known to science, and as the present list has been of slow scientific discovery, it is quite probable that new elements will be discovered as the world grows older. Some elements have names associated with them for ages—gold, silver, copper, iron, etc.; many others have been given Latin names by their discoverers—radium, platinum, etc. In chemical calculations abbreviations of the full names are used, or abbreviations of the Latin

equivalent; e. g. Iron—Fe (Ferrum), Barium—Ba. The complete list of known elements is given at the end of this chapter.

Until recent years it was thought that the atom was in truth the final sub-division of matter. The discovery of radium and radio-activity has now convinced scientists that atoms are merely aggregations of electrons, an electron being a unit of electrical energy. Chemistry, however, is concerned for the most part with the action of atoms, so we need give but little thought to the theory of electrons.

Physical and Chemical Changes Changes in matter are either physical or chemical. To illustrate the distinction let us consider the familiar changes that take place in water. The change from ice to water, and from water to steam, in no way changes the condition of the molecule, but only the **relation of the water-molecules each to the other.** You change the **form** of sugar or salt when you dissolve these substances in water, but this does not change the constitution of the sugar-molecule or the water-molecule. Such changes are physical, and not chemical.

If, however, two atoms of hydrogen gas are brought, under the right conditions, into contact with one atom of Oxygen gas, they combine to form a substance altogether different from either—the new substance being water, which is represented by the formula H_2O. This is a change on the part of the atoms to form **new molecules,** and is called a chemical change or **reaction.**

Elements have the inclination to unite or combine with certain other elements in a thoroughly systematic fashion. These various combinations always take place in exactly the same proportions. The attraction of elements for certain others is called "Chemical Affinity." Some affinities are stronger than others—for example, the affinity of iron for oxygen at high temperatures is strong; we see roll scale form very rapidly at the hot rolls in the iron or steel mills. This affinity between iron and oxygen is not so strong at atmospheric temperatures; the combination takes place more slowly and results in iron rust. These changes show that 2 atoms of iron combined with 3 atoms of oxygen, chemically to form a new substance which is iron oxide, Fe_2O_3.

Valence Elements vary in the number of atoms of other elements which they are able to hold in combination. One atom of hydrogen, for example, will combine with one atom of chlorine, two atoms with one of oxygen, three with one of nitrogen, and four with one of carbon. That property of an element which determines the number of atoms of another element that it can hold in combination is called "Valence." This is merely a numerical relation which conveys no information regarding the intensity of the affinity between atoms; yet a knowledge of valence is very important in determining theoretically, chemical reactions and in expressing them intelligibly. In all mensuration, there must be a standard for expressing values. Hydrogen has been selected as the valence standard and given the value 1, because scientists have determined that one atom of this element is never able to hold in

combination more than one atom of any other element. Reference to the table at the end of this chapter will show the valences of the elements.

Atomic Weights Why are some substances heavier than others? One cubic foot of iron weighs about twice as much as the same volume of aluminum; while a cubic foot of lead weighs nearly four times as much as the same-sized block of iron. The variations in the weights of different substances are due to the difference in weights of the atoms of the several elements. Atoms being so minute, it is naturally impossible to weigh them physically, so in chemistry they are weighed relatively—hydrogen being the approximate unit of weight. The atomic weight of Iron is 56, which means that an atom of Iron (Fe) is practically 56 times as heavy as an atom of hydrogen, which is 1.008 by weight.

Chemists are able to break up combinations and to establish new combinations. For example, by bringing together hydrochloric acid and zinc, the acid combination is broken up to form a new combination, zinc chloride and hydrogen. These processes are called "Reactions." It is by thus breaking down and building up, and calculating the changes that a chemical analysis is made.

Acids and Bases. We are accustomed to think of acids as liquids that have a sour taste and that "eat" or corrode other substances. To a chemist these substances have a more clearly defined meaning. Acids always contain hydrogen, among other elements.

For example, the molecule of hydrochloric acid contains one atom of hydrogen in combination with one of chlorine, according to the formula HCl; nitric acid is composed of one atom of hydrogen in combination with one of nitrogen and three of oxygen, according to the formula HNO_3; sulphuric acid consists of two atoms of hydrogen, one of sulphur and four of oxygen—H_2SO_4. These are just a few of the many acids, known to chemistry.

The "opposite" of an acid, so to speak, is an alkali or base. Acids cannot be discussed thoroughly except with respect to the relation they bear to bases. Potassium hydroxide, sodium hydroxide, calcium hydroxide and calcium oxide (lime) are some of the more common bases. A base, you see, has a metallic element in it.

When an acid and a base are brought together, each neutralizes the other. The metal in the base takes the place of the hydrogen in the acid, and a new substance called a Salt is formed. At the same time the hydrogen that is liberated from the acid combines with the oxygen from the base to form water (H_2O). A salt is a neutral substance, neither acid nor basic. These changes, or reactions, may be illustrated by using the symbols of the elements that took part in the reaction, in the form of a mathematical equation: H_2SO_4 (sulphuric acid) + 2 KOH (Potassium hydroxide) = K_2SO_4 (Potassium sulphate, the Salt) + $2H_2O$.
HNO_3 (nitric acid) + NaOH(Sodium hydroxide) = $NaNO_3$ (Sodium nitrate) + H_2O.
You will observe, of course, that the total number of atoms of any element on the left side of the equation is equal to the total number of that element on the right side, although the combinations are different.

These reactions are typical of the behavior of all acids and bases. You see now why you have been told to wet an acid stain on your clothes or your skin with ammonia which "kills" the acid; and why soap suds are an antidote for acid poisoning; and why you have taken a pinch of baking soda for an acid stomach—to mention a few time-honored household practices.

The litmus test is commonly used to determine whether a substance is basic or acid in character. Litmus dye is blue, and if a solution that is colored blue with litmus, or a strip of paper colored by the solution, is touched with an acid, the color is changed to red. If the colored solution or paper is then treated with a base or an alkaline solution, the blue color is restored.

Some substances which do not seem to be acid to the least degree, act like acids when brought into contact with basic substances. Silica (SiO_2), the common name for Silicon Di-oxide or quartz-sand, is classed as an acid because it neutralizes basic substances, such as Lime (CaO), to form a neutral salt called Calcium Silicate, $CaSiO_3$, which is a common slag in iron and steel practice. That is why nothing siliceous is allowed to come in contact with the basic materials in the bottom and sides of a basic open hearth furnace when it is hot—the furnace bottom would be fluxed or slagged out. In a blast furnace the silica in the ore and coke ash combine with the basic limestone—and the neutral slag that is formed is in fact a salt.

Alumina, Al_2O_3, or the oxide of aluminum, has the peculiar quality of acting in certain reactions either as an acid or as a base.

It is called a neutral compound, and is an important constituent of fire clays. Where basic or acid material is required, alumina serves either purpose. One of the familiar forms of aluminum oxide (or alumina "for short") is granular corundum or emery.

Fire-clays are salts—silicates of alumina; alumina having acted as a base in reaction with silica, $Si(OH)_4$. The pure clay substance which identifies fire-clays bears the formula Al_2O_3, $2SiO_2$, $2H_2O$. (This particular silicate is more fully discussed in Chapter II under the heading "Fire-Clays.") Another familiar silicate is Portland cement, which is made of silica, alumina, lime, gypsum, etc., in definite proportions, but in a diversity of forms, depending upon the locality and raw materials of the manufacturer.

Sometimes a slight reaction between the fire-brick linings in manufacturing equipment and the raw materials is a benefit, and the manufacturer makes a point of causing such reaction. For example, the protective coating that forms on the fire-brick lining of a Portland cement kiln is usually started by a reaction between the cement-making ingredients and the brick. A thin layer of the neutral coating forms by the action of silica and alumina as explained above, and it gradually thickens without further attacking the brick. The kiln operator makes such a change in his mixture or in his kiln temperatures as will start this reaction. After the coating has started, it protects the brick from further action unless the coating should be removed.

A glass furnace is simply a reservoir for active chemical operations involving acids and bases. "Glass Sand," which is almost pure silica (SiO_2), is the acid; salt-cake (sodium sulphate Na_2SO_4), and soda-ash (Na_2CO_3) are the principal bases. The salt, then, is a silicate of soda, or plain glass. All the chemicals that enter into a glass "Batch," as the glass-making mass of materials is called, are destructive of the fire-brick materials that build the tank (or reservoir) unless the brick are of extraordinary purity. "Glass House" refractories, therefore, are in favorable repute because they successfully resist the combined action of the chemicals and the high heats encountered in glass furnaces.

Many chemical reactions that long have been familiar, but which many observers have not understood, are quite simple when the elements that are involved are known. For instance, fire-brick in furnaces are often rapidly destroyed when a steam jet is used to prevent clinker from attacking the grate bars. In such cases, it will almost invariably be found that the coal used is very high in sulphur, which is driven off as a gas. The sulphur, the hydrogen of the steam (H_2O) and the oxygen of the steam and air, all combine to form sulphuric acid (H_2SO_4), which is the destructive agent, instead of the heat.

Vitrification Vitrification is a term that is used to indicate that the basic impurities in a clay have reacted with the silica to form a salt of glassy nature. If the centers of vitrification in a hard-burned fire brick could be colored for the purpose of making them visible, the surface of the specimen would

present a speckled appearance, the specks being small and separate. * An over-burned brick is one in which these points of vitrification have become so numerous and so large as to compose a large part of the brick, which is then in a "Glassified" condition. A paving block should be vitrified, as a glassy, non-absorbent texture is an advantage in a pavement. Most good building brick are semi-vitrified, vitrification having progressed sufficiently to give the brick the required degree of cold-crushing strength, without lowering the porosity below a desirable percentage.

A well-burned fire-brick of high quality, if examined under a powerful microscope, shows a very low degree of vitrification, but sufficient to impart to the brick the necessary physical strength.

"Reducing Flame"
"Reducing Atmosphere"
"Oxidizing Flame"

These terms are in frequent use in metallurgical operations. As they have some direct effect upon fire-brick that are subjected to their influences, it is well to be familiar with them.

A reducing flame is one that tends to reduce or liberate a metal from combination with its oxides. It is a flame that is burning with an insufficient quantity of oxygen, and, therefore, it takes for combustion purposes the oxygen that is combined with the metal (say iron oxide, Fe_2O_3). This naturally liberates or reduces the metal. All brick clays, building tile, etc., contain a low percentage of iron oxide. If the flames within the kiln that burn the brick during their manufacture, do not get sufficient air

*The bluish black "Iron Spots" so familiar to users of fire-brick, have no relationship to these "Centers of Vitrification."

(oxygen), the oxygen that is within the brick with the iron oxide and titanium oxide is seized upon, and the metals are partially reduced. This gives the brick a dark color but does not materially affect its quality. The interior of such a kiln would be an example of a "Reducing Atmosphere." When tests of fire-brick are being made, it is advisable to avoid a reducing atmosphere by giving access to plenty of air, as many experts consider the reducing conditions harmful to the specimen being tested, and the result misleading.

An oxydizing flame, reasoning to the contrary, is given more air than it needs for combustion, and the excess of oxygen is combined with the object in the flame, which is then said to be oxidized. A blue or colorless flame is an oxydizing flame—a yellow flame is reducing.

Combustion The rapid oxidation of carbonaceous substances is combustion, in the commonly accepted sense of the word. Oils and gases are compounds in several different proportions of carbon and hydrogen, which are called hydro-carbons, and also of carbon and oxygen. Complete combustion takes place when carbon is combined with sufficient oxygen to satisfy fully the affinity of these elements for each other. The resulting product is carbon di-oxide or carbonic acid gas, CO_2.

Incomplete combustion consists of the combination of carbon with one atom of oxygen instead of two, and the formation of carbon monoxide gas, CO ("mon" meaning one). This reaction liberates heat, but only about one-third the quantity liberated by complete com-

bustion and the formation of CO_2. Incomplete combustion is the result of incorrect firing methods, of course. Modern boiler furnaces that are stoker fired, and have a sufficient air supply (without an over supply) usually afford complete combustion in the practical sense.

Pure hydrogen gas burns with a colorless flame, at a temperature of 3452 degrees F.; it is one of the principal ingredients of producer gas and water gas, as will be noted further on. When H is oxidized the product of combustion is H_2O—water.

The engineer's problem is to secure complete combustion, or the combination of one atom of the carbon with two atoms of oxygen, so that the product of combustion will be CO_2 (and H_2O when gas fuel is used), which goes up the stack. If the waste gases in the stack contain about fourteen per cent of CO_2 and no CO, the practice may be considered perfect.

To avoid an over-supply of air, it is important to avoid a leakage of air through cracks in the walls of the settings. The first precaution is to use fire-brick that are neutral as to expansion and contraction, and also of a perfection of workmanship that facilitates the building of masonry with close joints. Brick that contract excessively at high temperatures leave numerous small crevices in the walls, and any considerable expansion opens up leaks that lower the efficiency of the furnace. The use of dependable plastic clay cement is most important in this connection.

Gas Producers We have been discussing incomplete combustion as something to be avoided, which is correct when maximum heat value is desired from fuel. However, there are important industrial operations that are based upon incomplete combustion; namely, the operation of gas producers and water gas machines.

In former years, a gas producer was a fire-brick chamber with a closed top, in which coal was burned with about half the air supply that was required for complete combustion. As the result, an atom of carbon combined with an atom of oxygen to form carbon monoxide gas, CO. (This combustible gas is more economical as fuel than raw coal when the manufacturing operation is of sufficient size to justify the equipment.) The modern producers are equipped with a steam jet also; air is impelled into the producer by the steam pressure.

The incandescent carbon decomposes the H_2O—steam—, appropriates the O to make CO, and liberates the hydrogen (H_2) which mixes with the CO gas. A typical analysis of producer gas is as follows: H, 15%; CO, 27; CH_4, 2%; CO_2, 4%; Nitrogen (N), 52%. Producer gas is the least efficient of all the common fuel gases, but has several other advantages that cause it to be widely used in manufacturing plants. The heats in a gas producer are not so high as to be a strain on a high-grade brick, but the texture of the brick should be dense, to resist the action of the steam, and the workmanship of the brick should be practically perfect.

A blast furnace for the production of pig iron, is in effect (if not by intention) a gas producer. The coke is first burned to CO_2, but on coming in contact with incandescent coke farther up in the furnace the gas gives up one atom of its oxygen, according to the equation $CO_2 + C = 2CO$. This carbon monoxide gas is the most powerful reducing agent in the separation of the metallic iron of the ore from its oxides. A large quantity of this combustible gas is taken off from the top of the furnace, and is used to heat the checker-brick in the hot blast stoves, for firing boilers and driving gas engines.

Water Gas Machines The generator of a water gas set is similar to the gas producer that has just been discussed. A generator is a large chamber which is heated to a much higher temperature than the ordinary gas producer, the minimum temperature required for the production of water gas being about 1800 degrees F. The fuel bed of coke is heated to incandescence by a blast of air. This raises the heat in the generator to the point at which steam is converted to CO and H_2 when a jet of steam is turned into the generator. As this operation reduces the temperature of the fuel chamber, the steam is then turned off while the air blast again is turned on for the purpose of restoring the working temperature. The air blast is usually on for about four minutes. Thus these alternate operations are kept up. The air blast and the products of combustion go off through the stack; only the gas that is made from the decomposition of steam goes to the carburetor —hence the term "Water Gas."

The water-gas, as it comes from the generator does not contain all the desired elements. It is, therefore, conducted into a second large steel chamber, called the carburetor, which is lined with fire-brick and filled with fire-brick checker work. Some authorities state that the brick should be spaced 3.1 inches apart to give the best results.

These checker brick have been pre-heated, and are continually re-heated to about 1350 to 1400 degrees F. at regular intervals while the air blast is on (via the generator). Then the air blast is turned off, a spray of pre-heated gas oil (a by-product of petroleum) is injected through a spray in the top of the carburetor, so that the spray of oil will impinge upon the hot brick-work.

The oil is thus volatilized or gasified. The resulting oil-gas and water gas is then conducted to the super-heater where the various gases formed are amalgamated. The gas leaves the super-heater at temperatures about 1300 to 1400 degrees F.

The fire-brick have much to do with the yields and smooth working of a water-gas plant. The carburetor checker brick must be refractory, the better to withstand the heats for considerable periods of time without fusion; they must withstand the frequent fluctuations of temperature without deterioration; they must not absorb the oil or carbon deposit, but must quickly vaporize it.

Combined Water Other terms for chemically combined water are "Water of Constitution" and "Water of Crystallization." Several rocks have a certain amount of water, H_2O, held in combination with their characteristic ingredients. The rocks of this character that are most familiar are fire-clays and quartz. Being chemically combined, the hydrogen and oxygen do not, strictly speaking, exist as water; the quantities of these elements are present in these rocks, however, in the same proportions that constitute water, H_2O. There is no appearance of moisture because of the presence of combined water. At temperatures of about 675 degrees F., combined water is driven off. The expulsion of combined water from fire-clays, which occurs at about 675 degrees F., is called "Calcining." The clays thus burned are called "Calcine" or "Grog." A plastic clay so treated loses its plasticity permanently. As fire-clays contain from 11 to 14 per cent of combined water, the loss of such a large portion of its bulk by calcination causes the mass to contract or shrink. Burned clays or grog do not absorb water and for that reason they are used in the manufacture of brick and tile in which a porous texture is desirable, and also to facilitate drying freshly-molded pieces without injury.

When limestone is burned in a lime kiln, not only H_2O, but also carbon di-oxide, CO_2, is driven off, leaving "quick" lime which is CaO. On exposure to the air for a long time, lime mortar slowly combines with the trace of CO_2 in the air, and thus becomes something like its original substance—limestone. After a substance has taken up water in chemical combination, it is said to be a hydrated compound.

INTERNATIONAL ATOMIC WEIGHTS
1916

Element	Symbol	Weight	Valence[1]	Electro-chem. equiva-lents, g. per amp.-hr.	Melting points	Boiling points
Aluminum	Al	27.1	3	0.3368	658.7	1800.0
Antimony	Sb	120.2	3	1.4966	630.0	1460.0
Argon	A	39.88	0		—188.0	—186.0
Arsenic	As	74.96	3	0.9324	850.0	450.0[2]
Barium	Ba	137.37	2	2.5619	850.0	
Bismuth	Bi	208.0	3	2.5854	271.0	1440.0
Boron	B	11.0	3		2350.0	
Bromine	Br	79.92	1	2.9814	—7.3	58.75
Cadmium	Cd	112.40	2	2.0955	320.9	778.0
Caesium	Cs	132.81	1		26.0	
Calcium	Ca	40.07	2	0.7477	810.0	
Carbon	C	12.05	4	0.1118	>3600.0	
Cerium	Ce	140.25	4		623.0	
Chlorine	Cl	35.46	1	1.3220	—101.5	— 37.6
Chromium	Cr	52.0	3	0.6476	1520 to >Fe	2200.0
Cobalt	Co	58.97	2	1.1000	1610[3]	
Columbium	Cb	93.1	5		1950–2200	
Copper	Cu	63.57	2	1.1858	1083.0	2100.0
Dysprosium	Dy	162.5				
Erbium	Er	167.7				
Europium	Eu	152.0				
Fluorine	F	19.0	1	0.7085	—223.0	—187.0
Gadolinium	Gd	157.3				
Gallium	Ga	69.9			30.1	
Germanium	Ge	72.5			958.0	
Glucinum	Gl	9.1			1800.0	
Gold	Au	197.2	3	2.4513	1063.0	
Helium	He	4.002	0		—271.9	—268.8
Holmium	Ho	163.5				
Hydrogen	H	1.008	1	0.03759	—259.0	—252.8
Indium	In	114.8			154.5	
Iodine	I	126.92	1	4.7303	114.0	184.35
Iridium	Ir	193.1	4		2300.0	
Iron	Fe	55.84	2	1.0404	1530± 5	2450.0
Krypton	Kr	82.92			—169.0	—151.7
Lanthanum	La	139.0			810.0	
Lead	Pb	207.20	2	3.8613	327.4	1525.0
Lithium	Li	6.94	1	0.2622	186.0	
Lutecium	Lu	175.0				
Magnesium	Mg	24.32	2	0.4531	651.0	1120.0
Manganese	Mn	54.93	2	1.0255	1260± 20	1900.0
Mercury	Hg	200.6	2	7.4803	—38.7	357.0
Molybdenum	Mo	96.0	2	1.7900	2500.0	
Neodymium	Nd	144.3			840.0	

[1] In those cases in which a metal has two valences, the valence given corresponds to the electrochemical equivalent, and may not necessarily be the commoner one.

[2] Sublimes.

[3] Commercial metal, about 1480° C.

INTERNATIONAL ATOMIC WEIGHTS
1916
Continued

Element	Symbol	Weight	Valence[1]	Electro-chem. equiva-lents, g. per amp.-hr.	Melting points	Boiling points
Neon	Ne	20.0	0		—253.0	
Nickel	Ni	58.68	2	1.0945	1452± 3	
Niton	Nt	222.4	0			
Nitrogen	N	14.01	3	0.1745	—210.5	—195.7
Osmium	Os	190.9			2700.0	
Oxygen	O	16.00	2	0.2983	—218.0	—183.0
Palladium	Pd	106.7	2	1.9951	1550.0	
Phosphorus	P	31.04			44.1	287.0
Platinum	Pt	195.2	4	1.8206	1755.0	
Potassium	K	39.10	1	1.4584	62.3	667.0
Praseody-mium	Pr	140.9			940.0	
Radium	Ra	226.0	2		900.0	
Rhodium	Rh	102.9			1940.0	
Rubidium	Rb	85.45			38.0	
Ruthenium	Ru	101.7			>1950.0	
Samarium	Sa	150.4			1350.0	
Scandium	Sc	44.1			1200.0 (?)	
Selenium	Se	79.2	2	1.477	218.5	690.0
Silicon	Si	28.3	4	0.2638	1420.0	
Silver	Ag	107.88	1	4.0248	961.0	1955.0
Sodium	Na	23.00	1	0.8596	97.5	742.0
Strontium	Sr	87.63	2	1.6333	>805,850< >Ca< Ba	
Sulphur	S	32.06	2	0.5980	116.5	444.5
Tantalum	Ta	181.5			2850.0	
Tellurium	Te	127.5	2	2.379	451.0	1390.0
Terbium	Tb	159.2				
Thallium	Tl	204.0			302.0	1700.0
Thorium	Th	232.4			>1700,0<Pt.	
Thulium	Tm	168.5				
Tin	Sn	118.7	2	2.2188	231.9	2270.0
Titanium	Ti	48.1	4	0.4490	1795.0± 15.0	
Tungsten	W	184.0	6	1.1437	3267	
Uranium	U	238.2			Near Mo.	
Vanadium	V	51.0			1720.0± 20.0	
Xenon	Xe	130.2	0		—140.0	—109.0
Ytterbium	Yb	173.5			1800.0 (?)	
Yttrium	Yt	88.7			1200.0 (?)	
Zinc	Zn	65.37	2	1.2194	419.3	918.0
Zirconium	Zr	90.6			2350.0 (?)	

See footnotes on page 31.



PLATE 3A—View Showing Electric Mining Machinery.



PLATE 3B—A Loaded Car of Clean, Hand-Picked Walsh Clay.



PLATE 4A—Making Up Trains.



PLATE 4B—At the Foot of the Shaft.

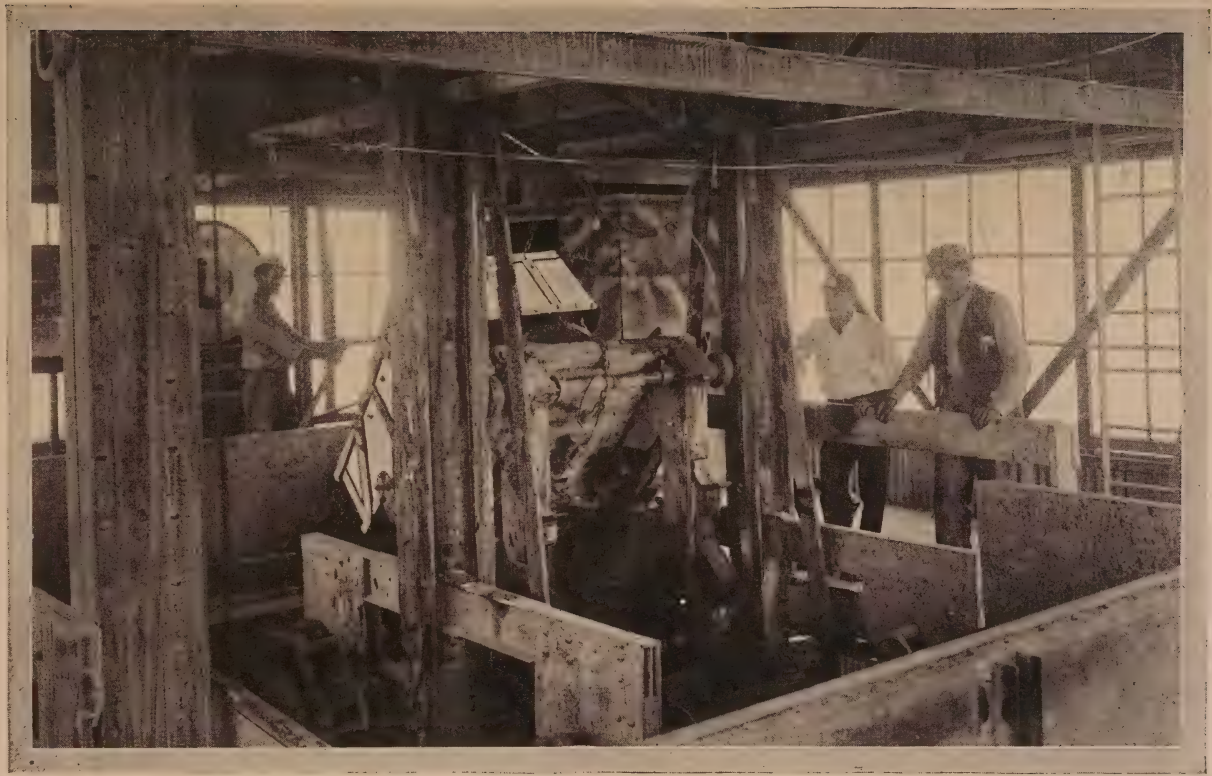


PLATE 5—Weighing and Inspecting in the Tipple.

CHAPTER IV

"Following Through" at the Walsh Plant

THE quality of a product depends upon the manufacturing ideals built into it; consequently, a knowledge of just how WALSH Fire Brick is made is helpful when determining the suitability of refractory materials for your own needs. It is naturally difficult to describe adequately the manufacture of fire-brick, but with the help of the illustrations appearing in this chapter, we have attempted to show how fire-bricks are made in the modern WALSH Plant.

In recent years the engineering profession has been giving increasing attention to the technology of refractories. A forward movement in the manufacture of fire-clay products, as represented by the construction of the new plant, was therefore timely, when it was erected in 1917. Operations were begun in 1918. The initial producing capacity was about 150,000 brick daily, with ample provision for expansion.

Mines Access to the clay deposits underlying the plant site and adjoining territory is by means of a concrete double shaft. The main entry extends back hundreds of feet past rooms that have already been mined. The entire mine is dry, electrically lighted and electrically equipped. After the face of the clay has been "shot down," it is inspected while being loaded by hand into mine cars (Plate 3B).

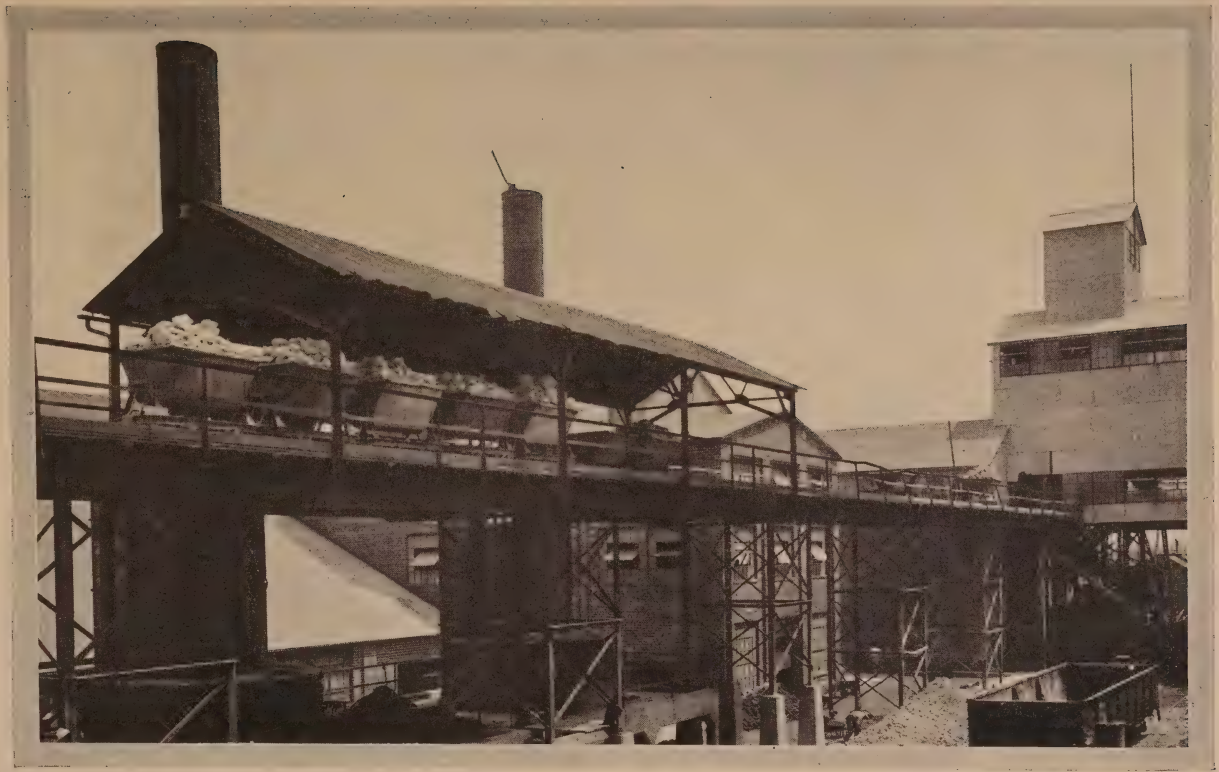


PLATE 6—Calcine Kilns.



PLATE 7—A Roll-Crusher and Belt Distributor.



PLATE 8A—One of the Storage Rooms for Crushed Crude Clay.



PLATE 8B—A Battery of "Dry Pans".

As a comparatively thin section of clay is being mined from a deposit which extends several feet above and below the mine proper, the clay is remarkably free from foreign substances.

For years prior to the construction of the WALSH Plant—the third WALSH factory—the company had owned in Missouri large areas of clay lands, representative of the purest in the state. Three varieties of clay; plastic, semi-flint and hard-flint are available in three strata of the mine contiguous to the Vandalia plant. Surveys show that the entire clay body is remarkably free from impurities. Hard-flint clays are also shipped to this plant from extensive mines from which the surface earth or "over-burden" has been stripped for the purpose of mining the clay by daylight or open-pit methods.

Mixing After the cars are loaded, they are conveyed by "Sam," "Red" and other well-known Missouri mules to the "trip-station" (Plate 4A), where trains are made up for the electric locomotives to haul to the hoists (Plate 4B). Once placed on the hoist, the manufacturing process may be said to have started, for at the top the clay is automatically dumped into the scale hopper (Plate 5), which in turn drops its burden into the first set of roll crushers.

A large part of the crude lump clay is taken to the Calcine Kilns (Plate 6), where it is burned to expel combined water. This burned clay is called "Grog" or "Calcine." It is later ground and screened in the manner described for raw clays, and then mixed with raw clay in the manufacture of refractories.

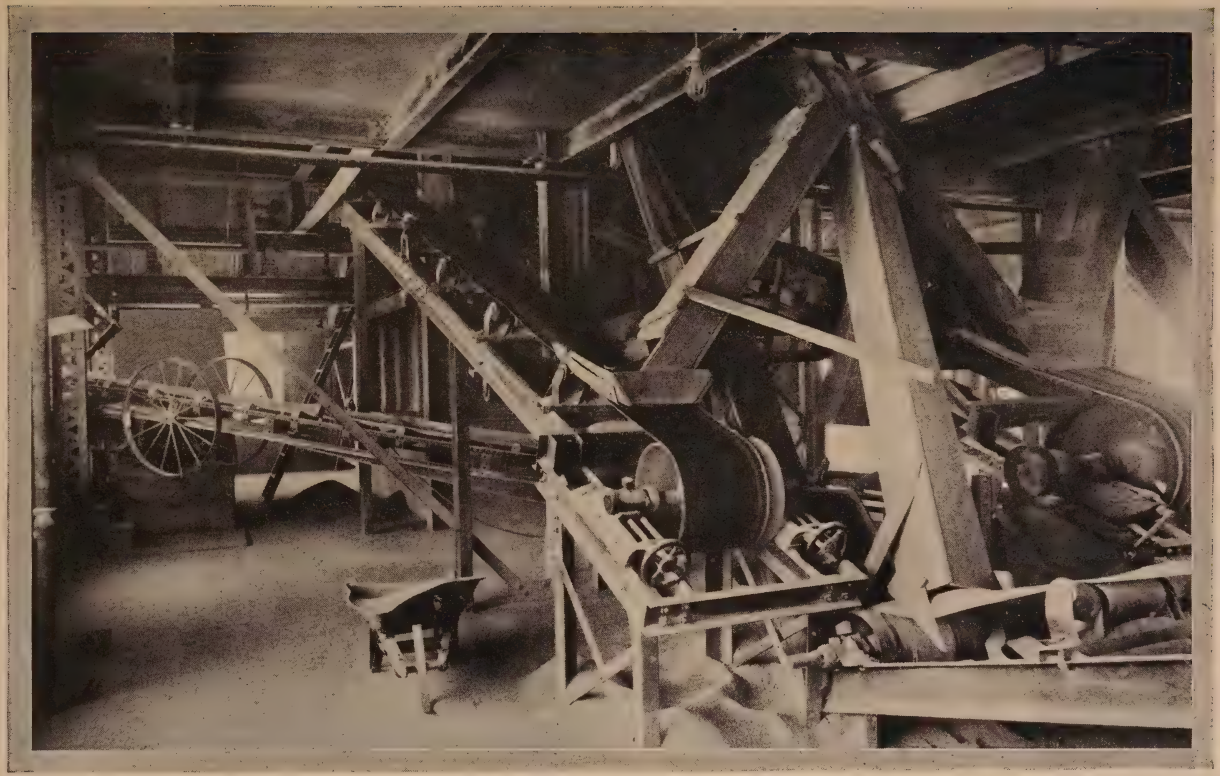


PLATE 9—Prepared Clay Distribution.



PLATE 10—A Battery of "Wet Pans".



PLATE 11—Loaded Buckets Being Brought to Molders' Tables by Mono-Rail Conveyor.

Because clay is gathered from all parts of the extensive mines, there is always a thorough admixture, but this is made doubly sure by passing it through a roll crusher and distributor, by means of which the material is conveyed to the various crude clay storage bins. The purpose of this careful mixing is to obtain a uniform average analysis and general character of brick-making material.

The third and final crushing is by means of "Dry Pans" (Plate 8B) of which there are now four at the WALSH Plant. Two are soon to be added. Perforations in the pan bottoms pass the granular clay via elevators, to the screens on the top floor, where the various sizes of prepared clay are separated and distributed by conveyors (Plate 9) to the prepared-clay bins. The granular texture of a brick or tile is specified to suit the purpose which it is to serve, and the storage bins at all times contain material screened to meet any requirement.

Walsh Processes "WALSH Brands" are made by four processes—*Special Hand Made*, "*Tempered*," "*Semi-open*," and "*Open*." Tile and specially designed shapes, with but few exceptions, can only be made by hand. The materials are "pugged" or mixed with water in "Wet-pans" (Plate 10) to the desired consistency, and emptied by automatic unloaders into steel buckets which are transported via an electric monorail conveyor to the molders' tables.

Hand Molded The molder's task is to produce a homogeneous tile or shape, free from interior defects or strains, and with a smooth, sharp finish.



PLATE 12A—These "Shapes" Are Bone Dry—Ready for the Kiln.



PLATE 12B—A Section of the Shape Drying Floor.

Special care is required that the shapes be dried properly. Perfectly molded pieces may be ruined during the drying process, although no defect may be apparent to the untrained eye. Plates 12A and 12B show some views of our drying floors. This department is constantly under the close superintendence of experts.

Tempered Standard sizes of bricks that must stand unusual "wear and tear," abrasion, pressure, blast, chemical action, clinker, etc., are made by the *Tempered* process. The clays are mechanically pugged with sufficient water to form a stiff, plastic mass, and are then forced by an auger machine through a die approximately the size of the face of a brick. This dense column of clay is automatically cut into "clots" or blanks, which are immediately formed by presses (Plate 13) into WALSH *Tempered* Brick. The pressed bricks are stacked in open order on dryer cars and placed in the tunnel dryers (Plate 15A) for drying before being set in kilns for burning.

Semi-Open In former years, if a *Tempered* brick was too dense for a specific purpose, the consumer was apt to use a "soft-mud" brick, which in the standard sizes, was re-pressed on hand presses. The texture of such a brick is friable and lacks the crushing and breaking strength, in most cases, that is the usual requirement in these latter days. As consumers found by experience that coarseness of grain had nothing to do with resistance to heat, they also found that a texture somewhat finer and produced under high pressure, yet sufficiently porous to withstand frequent and wide changes of temperature, provided the physical strength modern engineering demands.

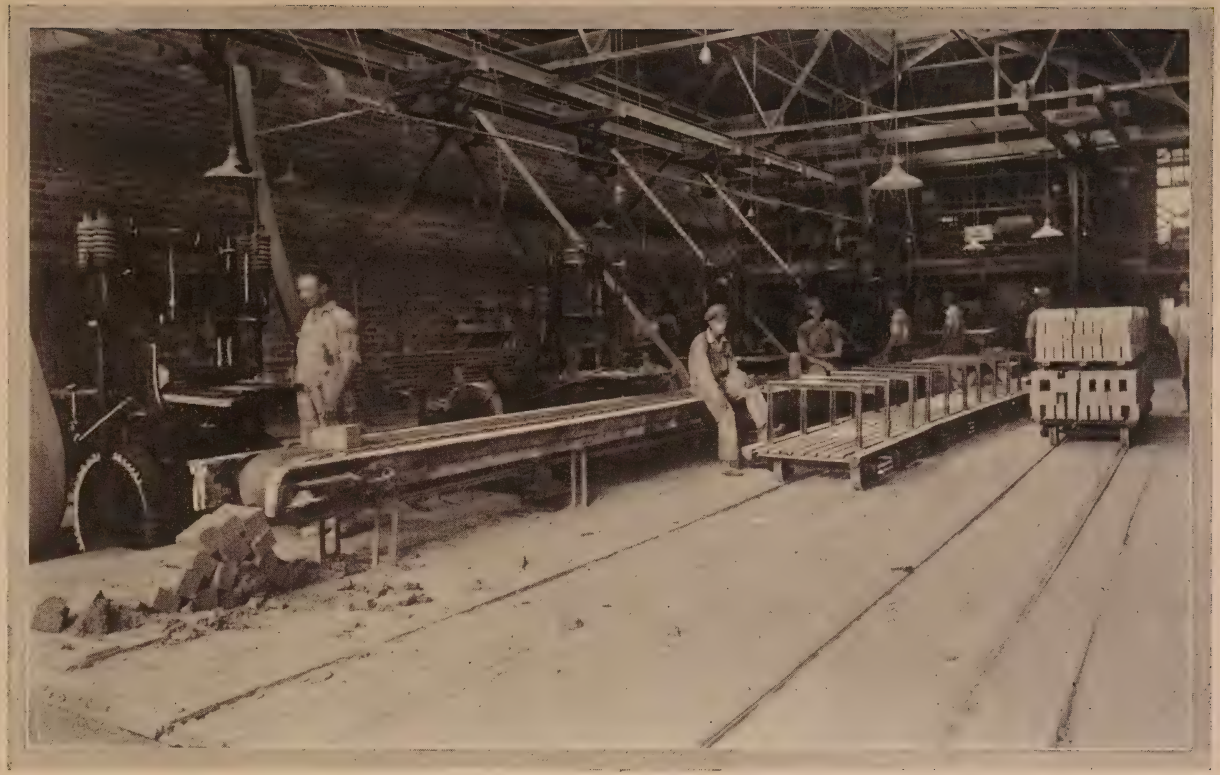


PLATE 13—Automatic "Tempered" Brick Machines.



PLATE 14—"Semi-Open" Brick Presses.

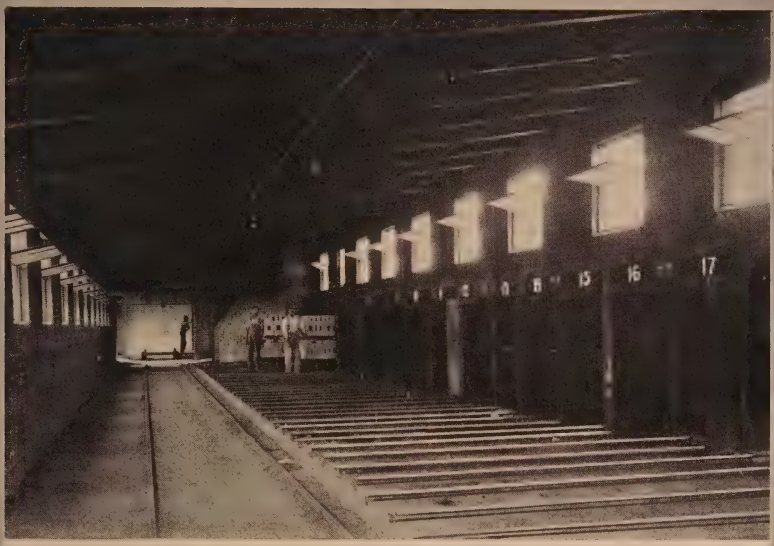


PLATE 15A—Charging End of Tunnel Driers.



PLATE 15B—Discharging End of Tunnel Driers.

Such a brick is the "Semi-Open." Plate 14 illustrates the machines which form brick of this texture. "Semi-Open" brick can be readily cut by the mason's tools, are sharp and accurately finished, and are uniform in size.

Burning The proper burning of clay wares required both scientific knowledge and suitable equipment. The equipment for burning at WALSH Plant was evolved by practical fire-brick operators in co-operation with engineering specialists. As "green" brick must be bone-dry before burning, tunnel dryers (Plate 15A) are provided. The kilns are fifty-two in number, each with a capacity of 48,000 bricks. Each kiln is equipped with an electric pyrometer which registers its temperatures at a central station in charge of the foreman of this department.

Producer gas is used for fuel. The raising or lowering of kiln temperatures, and the general conduct of the kilns while on fire is always under complete control of the operator in the instrument room. This fuel does not discolor the ware, which is "Bright" in appearance after being burned. Plate 15B shows a battery of kilns being charged or "Set" with bricks as they are brought from the dryer by the electric transfer car. Plate 16A shows this battery after the fires are on. Plate 16B is a view of the discharge side of a kiln battery with the loading tracks. (The square upright objects are gas flues.)



PLATE 16A—A Few of the Fifty-Two Kilns.



PLATE 16B—Discharge End of Kilns and Loading Dock—Storage Sheds on Right.

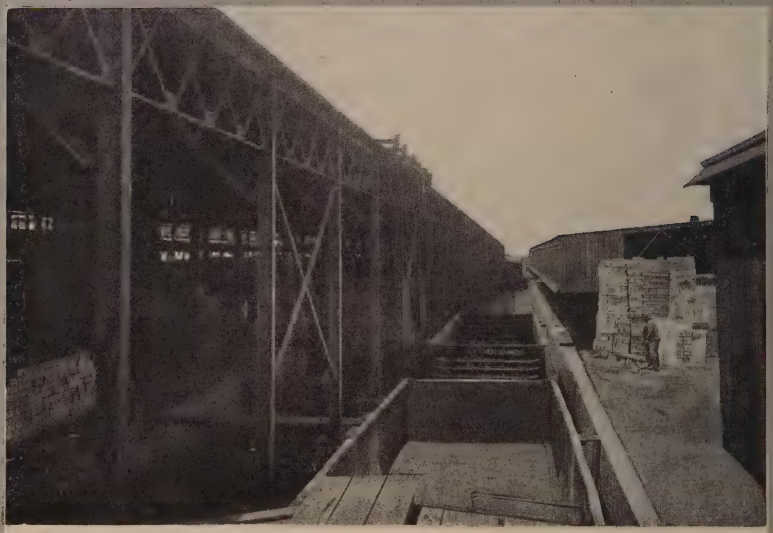


PLATE 17A—Two Loading Tracks—40 Box-Car Capacity.



PLATE 17B—View from top of Mine Hoist—Walsh Plant.

Annealing For the purpose of finishing clay products without interior strains, warps, cracks, etc., they must be carefully annealed. The scientific control of the kilns, which is mentioned in a preceding paragraph, makes perfect annealing possible. The kilns are fired in groups and cooled in groups. When burning is completed, one kiln receives the slightly cooler air from the adjoining kiln, and in turn passes it on to the next one. This slow cooling not only eliminates the danger of actual injury to the contents of the kiln, but it toughens and strengthens the product.

CHAPTER V

The Walsh Brands

TO MAINTAIN that any one brand of brick is suitable for every purpose is just as absurd as to claim that one medicine will cure any ailment. Although space is too limited to give a detailed description of all the varied uses of the WALSH Brands, some of the more important general purpose uses are given. WALSH Brick of several grades are regularly carried in stock sizes, under the following brands:

WALSH *Tempered* The WALSH Line

WALSH *Semi-Open*

WALSH XX WALSH X

Blast Furnace and Rolling Mill This department is under the direct supervision of an executive of wide experience in blast furnace and steel mill practice. The consumer's viewpoint is ours. All the processes that modern practice has approved, are applied to the products of our Iron and Steel Department.

Ladle Lining A special product of WALSH clays which is notably successful and long-lived in both iron and steel ladles.

Malleable Melting Furnaces The testimony of our malleable iron customers, as to the number of heats rendered by their bungs as well as from the side-walls, must be of interest to foundrymen who have felt the need of a wider market for satisfactory material for these purposes. One customer writes, "The losing of a bung since using your brick is something almost unheard of." The side-wall brick withstand the slag action and the wash of the metal exceptionally well.

Boiler Furnaces Modern steam engineering has created a more urgent demand for furnace material that will stand the high heats required in the newer large installations. The use of fuel oil and powdered coal to an increasing extent, the greater height of the furnace walls, improved automatic stokers, the demand for high efficiency generally —all these factors have focused attention upon fire-brick equal to every requirement. The records made by WALSH Brands in large power plants will interest operating executives. Many sizes and shapes besides those illustrated are carried in stock; tell us your requirements. Special designs will be made to order.

Water-Gas Lining For the generator a well-burned, low-shrinkage brick of great strength and toughness is required, because of the frequent removal of clinker and the action of steam. For the carburetor, a checker and lining brick has been developed that is uncommonly durable. Being made from a refractory mixture, the checker work is taken down with but a slight loss of brick. The texture is such as quickly gasifies the oils with the least deposition of carbon. WALSH linings are almost always the means of increasing the yield of gas with reduced consumption of oil.

Rotary Kiln Linings These blocks, being practically neutral as to expansion and contraction, hold the coating which is readily taken on by the hot zone liners. The materials for the cooler portions of the kiln are made of refractory clays for safety. Their resistance to abrasion, together with the durability of the hot zone blocks, have made WALSH Liners popular with cement manufacturers.

Checker Brick—Open Hearth and Glass Furnaces A development for maximum service under the conflicting conditions of most checker chambers. It furnishes great resistance to slags, flue dust and spalling action, and yet provides for proper absorption and radiation of heat. All regular sizes and shapes are carried in stock.

Cupola Linings Because the cupola could be "daubed" every morning many foundrymen were accustomed to pay little attention to the quality of the linings. It is a fact, now generally accepted, that the highest grade of fire-clay material in cupolas is real economy.

Forging and Re-heating Furnaces The use of fuel oil in a small combustion chamber, with the hard driving practiced in most forge shops, has developed a demand for a super-brick for lining these furnaces. We have been successful in supplying the need.

Petroleum Refineries This phase of our business is equal in importance to any on our books. Operators of international repute are consistent users of WALSH Brands.

Lead, Zinc and Copper Smelting Many notably high-grade clays fail to meet the severe service requirements of these industries. WALSH Brands have been developed by many years use in eastern and western plants, and are exceptionally well adapted to these purposes.

Shapes Made to Special Design A variety of clay mixtures is used in the Special Shapes and Tile Department, a part of which is illustrated on pages 42 and 45. The WALSH Plant has daily producing capacity of more than 155 tons of special shapes and tile, and is, therefore, prepared to serve the needs of the trade effectively. Full information regarding the conditions governing the use of such material should always be furnished with the inquiry or order, so that proper material may be specified by us.

Space in this book does not permit a detailed account of the service being rendered by WALSH Brands in many lines of industry other than those described. Special attention has been given to the material that is most frequently the subject of correspondence. We solicit the opportunity to submit detailed information concerning the application of our products to industries, such as:

Annealing Ovens and Furnaces,
Coke Ovens,
Clay-burning Kilns,
Enameling Furnaces,
Frit Furnaces,
Lime Kilns,
Locomotives,
Muffles,
Steel Treating—Heating Furnaces.

Our Engineering Department is always ready to consult with manufacturers on their refractory problems.


NAASH FIRE-CLAY PRODUCTS CO.
NFCP BRANDS
SAINT LOUIS
STANDARD 9" SHAPES
9" STRAIGHT.
9" × 4½" × 2½"
SMALL 9" BRICK
9" × 3½" × 2½"
SPLIT BRICK
9" × 4½" × 1¼"
2" BRICK
9" × 4½" × 2"
SOAP
9" × 2¼" × 2½"
CHECKER
9" × 2¾" × 2¾"
Nº 1 WEDGE
9" × 4½" × (2½" - 1⅞")
Nº 2 WEDGE
9" × 4½" × (2½" - 1½")
Nº 3 WEDGE
9" × 4½" × (3" - 2")
Nº 1 KEY
9" × (4½" - 4") × 2½"
Nº 2 KEY
9" × (4½" - 3½") × 2½"
Nº 3 KEY
9" × (4½" - 3") × 2½"
Nº 4 KEY
9" × (4½" - 2½") × 2½"

WALSH FIRE-CLAY PRODUCTS CO. GRANITE WALSH SAINT LOUIS

STANDARD 9" SHAPES



No 1 ARCH.
9" × 4½" × (2½"-2⅞")



No 2 ARCH.
9" × 4½" × (2½"-1¾")



No 3 ARCH.
9" × 4½" × (2½"-1")



No 1 NECK.
9" × 4½" × 3½" × 2½" × ⅝"



No 2 NECK.
9" × 4½" × 1½" × 2½" × ⅝"



No 3 NECK
9" × 4½" × (2⅜"-⅝")



JAMB BRICK.
9" × 4½" × 2½"



END SKEW.
(9" × 6¾") × 4½" × 2½"



SIDE SKEW.
9" × (4½"-1¾") × 2½"



EDGE SKEW.
9" × (4½"-1½") × 2½"



FEATHER EDGE.
9" × 4½" × (2½" × ⅛")

STANDARD 9" SHAPES



CIRCLE BRICK
(9" - 4½" x 2½")

NAME	DIMENSIONS	DIAMETER INS	DIAMETER OUTS	№ TO CIRCLE
24" CIRCLE	(9" - 6 $\frac{13}{32}$") x 4½" x 2½"	24	33	12
36" "	(9" - 7 $\frac{9}{16}$") x 4½" x 2½"	36	45	16
48" "	(9" - 7 $\frac{19}{32}$") x 4½" x 2½"	48	57	20
60" "	(9" - 7 $\frac{13}{16}$") x 4½" x 2½"	60	69	24
72" "	(9" - 8") x 4½" x 2½"	72	81	28
84" "	(9" - 8 $\frac{1}{8}$") x 4½" x 2½"	84	93	33

LARGER THAN 9" SHAPES



13½" № 1 WEDGE.
13½" × 6" × (3" - 2¾")



13½" № 2 WEDGE.
13½" × 6" × (3" - 2½")



13½" STRAIGHT.
13½" × 6" × 2½"
ALSO 13½" × 6" × 3"



13½" № 1 KEY.
13½" × (6" - 5") × 2½"
ALSO 13½" × (6" - 5") × 3"



13½" № 2 KEY.
13½" × (6" - 4⅜") × 2½"
ALSO 13½" × (6" - 4⅜") × 3"

SHAPES FOR MALLEABLE FURNACES



ARCH BUNG.
9" × 4½" × (2½" - 2⅜")



№ 101 SQUARE BUNG.
13" × 4½" × 3"



№ 103 ARCH BUNG.
13" × 4½" × (3" × 2⅜")



№ 102 ANGLE BUNG.
(11⅜" - 12¾") × 4½" × 3"



№ 104 ARCH ANGLE BUNG.
(11⅜" - 12¾") × 4½" × (3" - 2⅜")



№ 105 ARCH BUNG.
13" × 4½" × (3" × 2⅜")

WALSH REF. CLAY PRODUCTS CO. WALSH BRAND ST. LOUIS

LARGER THAN 9" SHAPES



LARGE 9"
9" × 6¾" × 2½"



LARGE 9" Nº1 WEDGE.
9" × 6¾" × (2½" - 1⅞")



LARGE 9" Nº2 WEDGE.
9" × 6¾" × (2½" - 1½")



9" × 6" × 2½" STRAIGHT.
ALSO 9" × 6" × 3"



Nº1 FLAT BACK ARCH.
9" × 6" × (3½" - 2½")
Nº2 FLAT BACK ARCH.
9" × 6" × (3½" - 2").



9" × 6" Nº1 KEY
9" (6" - 5⅜") × 2½"
ALSO 9" (6" - 5⅜") × 3"



9" × 6" Nº 2 KEY.
9" × (6" - 4⅜") × 2½"
ALSO 9" × (6" - 4⅜") × 3"



OPEN HEARTH CHECKER.
9" × 4½" × 4½"
10" × 4½" × 4½"
10½" × 4½" × 4½"
10½" × 4½" × 4½"
12" × 4½" × 4½"



CUPOLA BLOCKS
(9" —) × 9" × 4½"

SIZE	INSIDE DIA.	OUTSIDE DIA.
Nº A	18"	25"
Nº B	21"	30"
Nº C	27"	36"
Nº D	30"	39"
Nº E	40"	49"
Nº F	51"	60"
Nº G	60"	69"
Nº H	73"	82"

WALSH FIRE CLAY PRODUCTS — WALSH BRANDS — EAST LIVERPOOL, OHIO

LARGER THAN 9" SHAPES



9"×9" STRAIGHT
9×9×3½
ALSO 13½×9×3½



9×9 ARCH
9×9×(3½-)
ALSO 13½×9×(3½-)
FOR ARCHES 3'0, 4'0 & 5'0 INSIDE DIAMETER

3'0" DIA	9×9×(3½-2⅝)	13½×9×(3½-2⅝)
4'0" DIA	9×9×(3½-2⅜)	13½×9×(3½-2⅜)
5'0" DIA	9×9×(3½-2⅛)	13½×9×(3½-2⅛)



CUPOLA BLOCKS
(9"-)×6"×4"

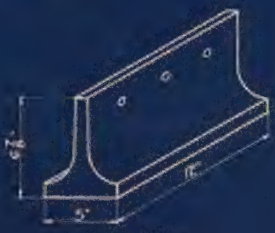
Nº OF BLOCK	DIAMETER INSIDE	DIAMETER OUTSIDE	Nº TO CIRCLE
30	30"	42"	15
36	36"	48"	17
42	42"	54"	19
48	48"	60"	21
54	54"	66"	23
60	60"	72"	25
66	66"	78"	27
72	72"	84"	29

WALSH FIRE-CLAY PRODUCTS CO. WALSH BRANDS EST. 1868

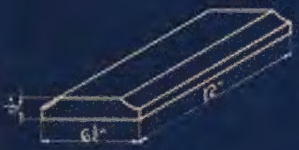
BOILER SHAPES



Nº 201



Nº 202



Nº 205



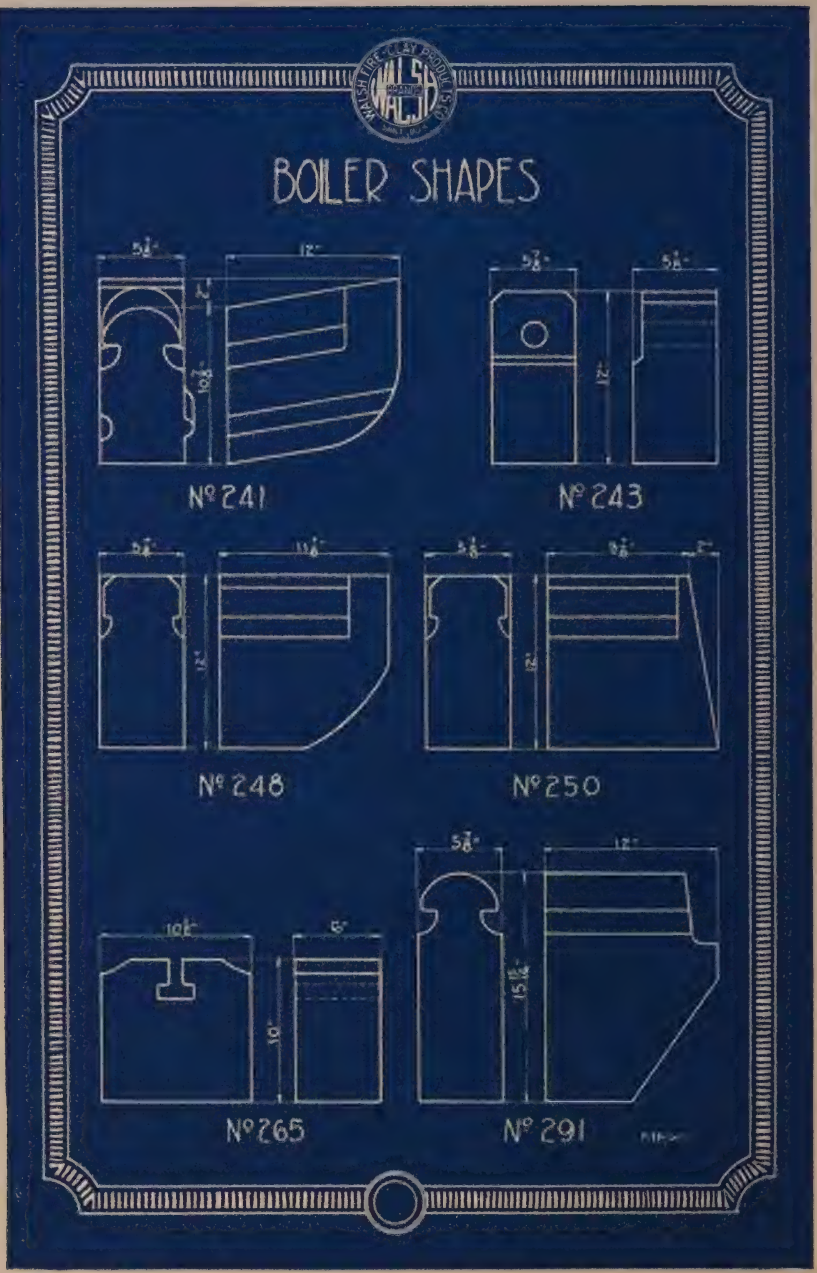
Nº 206

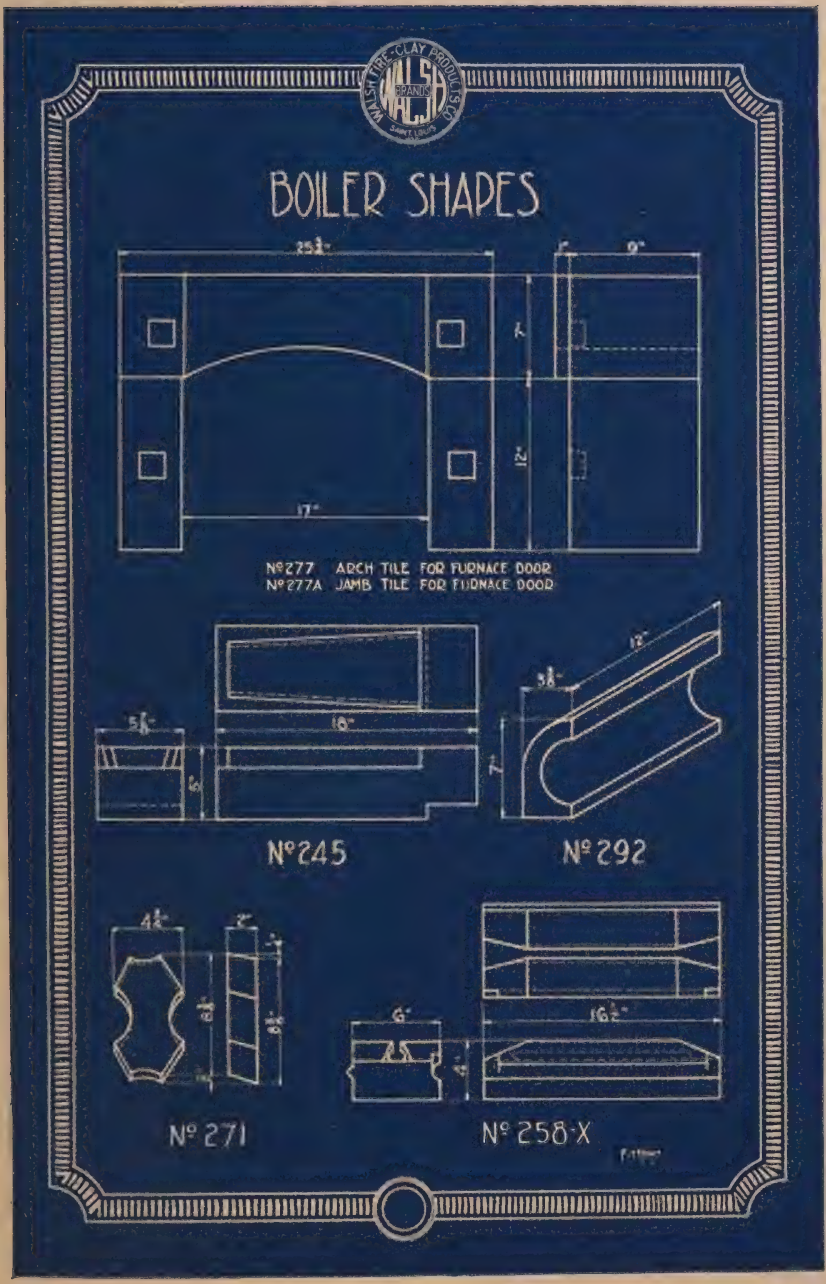


Nº 275



Nº 276


BOILER SHAPES
Nº 241
Nº 243
Nº 248
Nº 250
Nº 265
Nº 291


WALSH FAIRMOUNT CLAY PRODUCTS CO.
WALSH FRANCIS
ST. LOUIS
BOILER SHAPES
25½"
9"
17"
Nº277 ARCH TILE FOR FURNACE DOOR
Nº277A JAMB TILE FOR FURNACE DOOR
5⅛"
10"
18"
5⅛"
Nº245
Nº292
4½"
2"
G"
16½"
Nº 271
Nº 258-X

High Alumina Refractories For the reason that the Oxide of Aluminum, or Alumina, resists the effect of heat up to 3722 degrees F., there has been a desire on the part of brick manufacturers to utilize various highly aluminous materials for the manufacture of refractories. In former years efforts toward this end were not entirely successful. Brick made of bauxite, an ore of aluminum, were not capable of withstanding changes of temperature, and they shrank excessively at working temperatures.

The Walsh ↩ Brands of refractories represent a new development in highly aluminous materials. These bricks do not shrink or spall in service, to any considerable degree. The standard 9-inch sizes and special shapes are produced with graduated contents of alumina. The resistance of these brands to heat is indicated by the temperatures at which samples soften in the laboratory, ranging from Cone 34-35 (representing about 3310 degrees F., by Orton's temperature table, or about 3180 degrees F. by the table of the Bureau of Standards), to Cone 37-38 (about 3416 degrees F., according to Orton, or 3290 degrees F., according to the Bureau of Standards).

The Walsh ↩ Line is recommended for equipment which is uncommonly destructive of fire-brick—such as electric furnaces, high powered boiler furnaces, large forges, rotary kiln linings for lime and Portland cement manufacturing, etc

"Mon-O-Frax" High Temperature Cement *Mon-O-Frax* Cement is recommended for use as mortar for brick laying, or as a binder for ground fire-brick when ramming-in patches or baffles. When used as mortar it should be carefully mixed with water, so as to have the "thick soup" consistency without allowing the water to run off. The joints should be as thin as possible.

As a binder for ground fire-brick, the moistened *Mon-O-Frax* should be well worked to develop maximum plasticity. Use as stiff as possible. This cement is highly refractory, sets hard in air, and is practically neutral as to expansion and contraction.

Mon-O-Frax Cement is shipped dry in cloth bags.





PLATE 19A—Walsh Material Being Installed in Furnace of Illinois Glass Company, Alton, Illinois. (Eleven Furnaces at This Plant.)

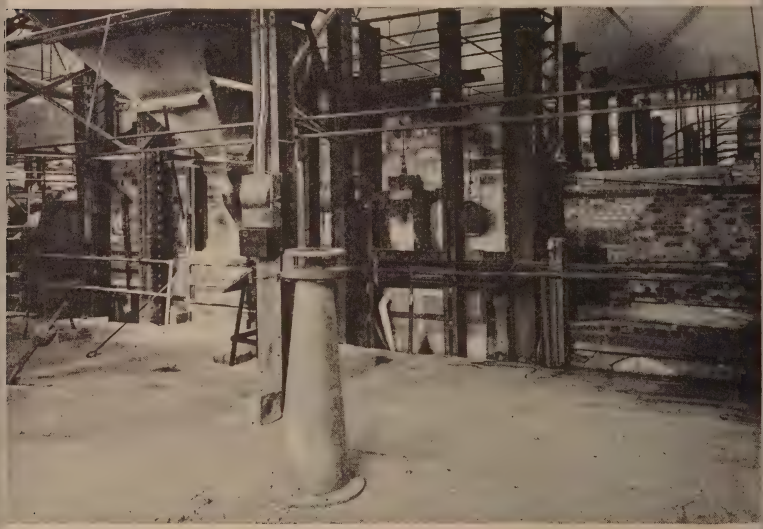


PLATE 17B—Furnace of the Illinois Glass Co., Alton, Ill., Walsh Material Installed.

CHAPTER VI

Glass Furnace Material

THE Glasshouse Refractories Department, the pioneer organization of the WALSH institution, is located in St. Louis, near the affiliated factories of the Mississippi Glass Company.

There are advantages in being a pioneer. Our working force—foremen, superintendent, assistants, etc.—is composed of men who have been employed at this plant continuously for many years. Their understanding of the extreme care that is exercised in the selection and preparation of the raw materials, and their skill in molding and finishing the products have been highly developed during years of specializing on the manufacture of glass furnace material.

Manufacture The clays used in the manufacture of *Tank Blocks* (flux and refractory), as glass furnace linings are commonly termed, are the best obtainable. Notwithstanding this fact, the selected plastic clays are thoroughly weathered and "washed" at the factory to remove the smallest particles of impurities that may be present.

Some of the washed clay is burned in the form of rectangular blocks (Plate 20). Definite proportions of this washed and burned material are ground and screened. This is an important part of the final mixture from which *Tank Blocks* are made.

When all the ingredients of a WALSH Glass Furnace Block have been thoroughly mixed and pugged to a plastic mass, the prepared clay is stored in great piles for maturing and "aging" (Plate 21).



PLATE 20—Burnt Washed Clay Used in Glass Refractories Manufacture.

These piles are kept for months covered with wet cloths to prevent drying out and hardening. During this time a mysterious process is going on within the mass which adds a valuable bonding quality to the materials.

After the right period of "aging," the clay is again mixed by automatic machinery. A stock of this "aged" prepared clay, always kept in the right condition for molding, is kept on each molding floor of the Glass Refractories Department (Plate 22).

The molded shapes are allowed to remain on the floor for several months, so that they may dry slowly and thoroughly without cracking, warping or developing interior imperfections. Plates 23, 24 and 25 show that flux and refractory material is not only heavy but often of fairly intricate design. When the blocks are absolutely dry they are dressed to true surfaces and angles as per blue prints.

Setting large blocks for burning (Plate 26) is a job that requires experience and great care. Burning, likewise, must be done under the direction of skilled men.

The neighboring plants of the Mississippi Glass Company, in which are produced wired glass and figured sheet glass, serve the refractories plant in the capacity of a practical testing laboratory—to their mutual advantage. Thus, the clay materials offered to the trade are those that have been thoroughly demonstrated in actual practice.

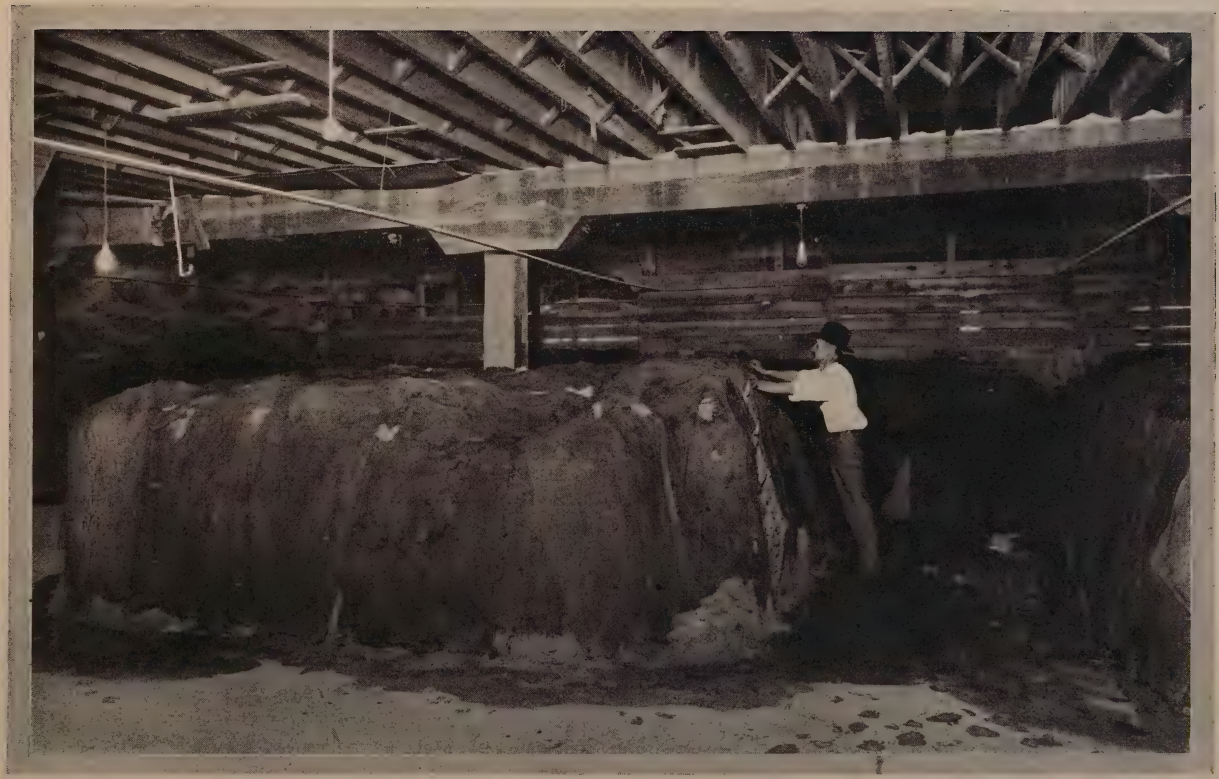


PLATE 21—Prepared Clay "Aging" for Glass Furnace Material—St. Louis Plant.



PLATE 22—View of One of Our St. Louis Molding Floors—Prepared Clay in Background.

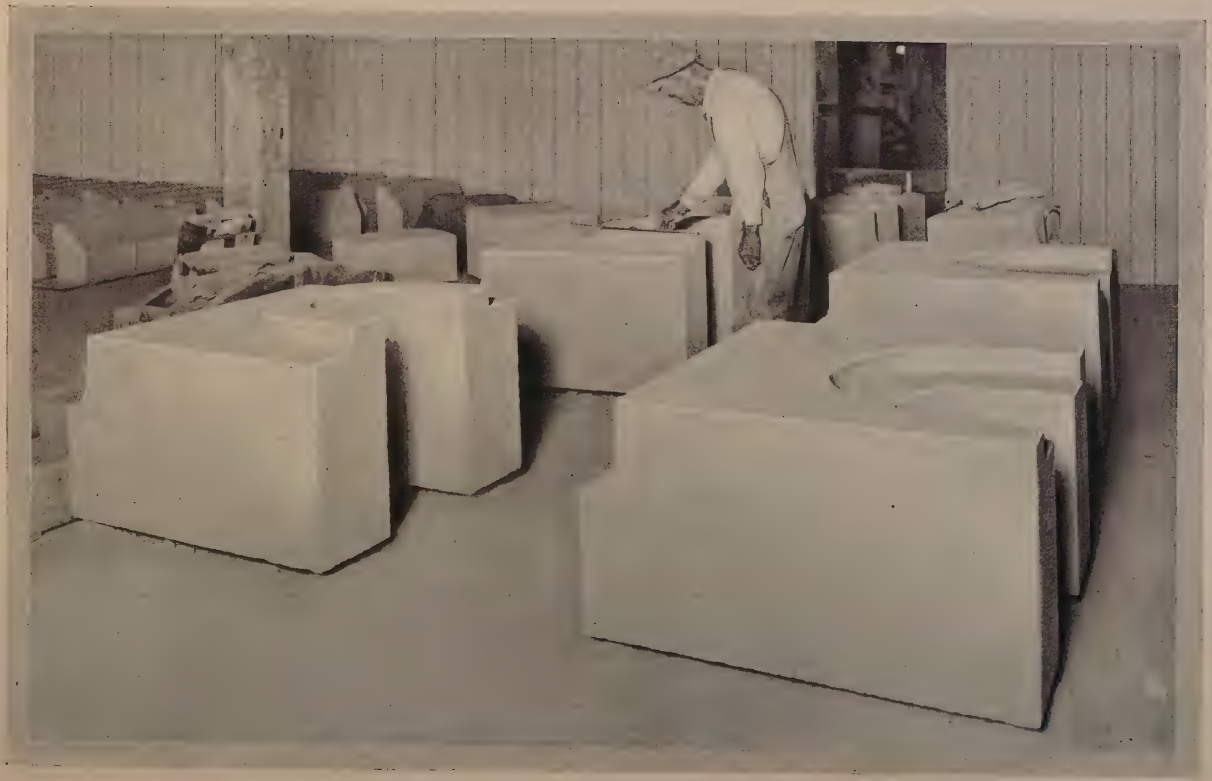


PLATE 23—Blocks and Special Shapes Weighing 3000 Pounds Are Not Uncommon.

Flux Blocks The stock sizes are fifty-three in number, and range from size 6x12x18 to 14x18x24. The most popular sizes are listed as follows:

Trued for 12″ Wall	Trued for 16″ Wall	Trued for 18″ Wall
12x12x18	12x16x18	12x18x18
12x12x24	12x16x24	12x18x24
12x12x30	12x16x30	12x18x30
12x12x36	12x16x36	12x18x36
12x12x42	12x16x42	12x18x42
12x12x45	12x16x45	12x18x45
12x12x48	12x16x48	12x18x48
12x18x18		
12x18x24		
12x18x30	Miscellaneous	
12x18x36		
12x20x24	12x24x42	12x36x36
12x24x24	12x24x48	12x36x42
12x24x30		12x36x48
12x24x36		

Tank Blocks

Trued for 12″	Bottom Grade	Stock Sizes
12x12x24	12x16x30	
12x12x30	12x16x36	
12x12x36	12x18x24	
12x16x24	12x18x30	
	12x18x36	

Refractory Blocks

Stock Sizes	
6x12x18	6x12x30
6x12x24	6x12x36



PLATE 24—Some of the Shapes Are Not Only Heavy, But Intricate in Design.

A Complete Service Individual plant conditions vary to so great an extent that it would be impracticable to list in this book all the detailed dimensions, weights, etc. of all the articles which we make for glass furnaces. The WALSH Engineering Department, with its specialists in glass furnace practice, is always ready to serve glass manufacturers. Best results are obtained through these personal efforts of our representatives. We give prompt attention to inquiries for the following items:

Arch Blocks
Breast Wall Brick
A. Q. Jack Arches
Blow Furnace Rings
Bottom Blocks for Lehr Floor—Refractory Material
Bridge Cover Blocks
Cap Skew Blocks
Checker Tile
Dog House Angle Blocks—Flux Grade
Dog House Angle Blocks—Pot Clay Grade
Dog House Arch Blocks
Floaters
Gathering Ring Stones
Gathering Hoods—Flux Grade
Glory Hole Rings
Glory Hole Solid Cap Bricks
Lehr Tile
Mantle Blocks for Flattening Ovens
Muffle Tile
Natural Gas Burner Blocks
Owens Machine Plugs
Pillar—Inverted Arch and Eye Brick
Plugs

Continued on Page 81



PLATE 25—View of a Drying Floor in the St. Louis Plant, Showing Blocks Ready for Dressing.

GLASS FURNACE ITEMS

Continued from Page 79

Port E Blocks
Pots—Thread
Pot Setting Brick
Producer Blocks
Regenerative Furnace Arch and Skew
Recuperator Tile
Revolving Furnace
Ring—Tank—Gathering
Shade Stones
Shear Cakes
Special Producer Blocks
Tank Rings
Thread Pots
Tuck Stones
Thimble Blocks
Throat Blocks

Clays With the wide variety of special shapes which we furnish to glass manufacturers, we supply every requirement for clays:

Prepared Pot Clay
Prepared Flux Clay
Bench Clay—Wet or Dry
Special Eye Facing Clay
Mending Clay—Prepared or unprepared
Stopper Clay
Missouri Washed Clay
Missouri Washed Clay Burned
Missouri Picked Pot Clay Raw and Burnt
Missouri Raw Furnace Clay
Bottom Grade Clay
Refractory Grade Clay
Jack Brick Grade Clay

These materials are not only mined from superior deposits, but are prepared by experts with the co-operation of our glass house engineers.



PLATE 26—Tank Blocks Set—Ready for Burning.



PLATE 27—"The End of a Perfect Day"—Vandalia Mine.

USEFUL INFORMATION

TABLE OF WEDGE BRICK

Inside Diameter	No. 2 Wedge	No. 1 Wedge	Straight	Total
2 ft. 3 in.	57			57
2 " 6 "	49	11		60
3 " 0 "	38	30		68
3 " 6 "	26	50		76
4 " 0 "	12	71		83
4 " 6 "		91		91
5 " 0 "		91	8	99
5 " 6 "		91	15	106
6 " 0 "		91	23	114
6 " 6 "		91	30	121
7 " 0 "		91	38	129
7 " 6 "		91	45	136
8 " 0 "		91	53	144
8 " 6 "		91	60	151
9 " 0 "		91	68	159
9 " 6 "		91	76	167
10 " 0 "		91	83	174
10 " 6 "		91	91	182
11 " 0 "		91	98	189
11 " 6 "		91	106	197
12 " 0 "		91	113	204
12 " 6 "		91	121	212
13 " 0 "		91	128	219
13 " 6 "		91	136	227
14 " 0 "		91	143	234
14 " 6 "		91	151	242

TABLE OF WEDGE BRICK

Continued

Inside Diameter	No. 2 Wedge	No. 1 Wedge	Straight	Total
15 ft. 0 in.		91	158	249
15 " 6 "		91	166	257
16 " 0 "		91	173	264
16 " 6 "		91	181	272
17 " 0 "		91	188	279
17 " 6 "		91	196	287
18 " 0 "		91	203	294
18 " 6 "		91	211	302
19 " 0 "		91	218	309
19 " 6 "		91	226	317
20 " 0 "		91	233	324
20 " 6 "		91	241	332
21 " 0 "		91	248	339
21 " 6 "		91	256	347
22 " 0 "		91	263	354
22 " 6 "		91	271	362
23 " 0 "		91	278	369
23 " 6 "		91	286	377
24 " 0 "		91	293	384
24 " 6 "		91	301	392
25 " 0 "		91	308	399
25 " 6 "		91	316	407
26 " 0 "		91	323	414
26 " 6 "		91	331	422
27 " 0 "		91	338	429
27 " 6 "		91	346	437

TABLE FOR ARCH BRICK

Inside Diameter	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
0 ft. 6 in.	19				19
1 " 0 "	12	15			27
1 " 6 "	4	30			34
1 " 9 "		38			38
2 " 0 "		34	8		42
2 " 6 "		26	23		49
3 " 0 "		19	38		57
3 " 6 "		11	53		64
4 " 0 "		4	68		72
4 " 3 "			76		76
4 " 6 "			76	4	80
5 " 0 "			76	11	87
5 " 6 "			76	19	95
6 " 0 "			76	27	103
6 " 6 "			76	34	110
7 " 0 "			76	42	118
7 " 6 "			76	49	125
8 " 0 "			76	57	133
8 " 6 "			76	64	140
9 " 0 "			76	72	148
9 " 6 "			76	79	155
10 " 0 "			76	87	163
10 " 6 "			76	94	170
11 " 0 "			76	102	178
11 " 6 "			76	109	185
12 " 0 "			76	117	193

TABLE OF 9-INCH KEY BRICK

Inside Diameter	No. 4 Key	No. 3 Key	No. 2 Key	No. 1 Key	Total
1 ft. 6 in.	25				25
2 " 0 "	16	13			29
2 " 6 "	9	25			34
3 " 0 "		38			38
3 " 6 "		29	13		42
4 " 0 "		21	25		46
4 " 6 "		12	38		50
5 " 0 "		5	50		55
5 " 3 "			57		57
5 " 6 "			55	4	59
6 " 0 "			50	13	63
6 " 6 "			46	21	67
7 " 0 "			42	29	71
7 " 6 "			38	38	76
8 " 0 "			34	46	80
8 " 6 "			29	55	84
9 " 0 "			25	63	88
9 " 6 "			21	71	92
10 " 0 "			17	80	97
10 " 6 "			13	88	101
11 " 0 "			9	96	105
11 " 6 "			4	105	109
12 " 0 "				113	113

TABLE OF 9-INCH KEY BRICK

Continued

Inside Diameter	No. 1 Key	Straight	Total
12 ft. 6 in.	113	4	117
13 " 0 "	113	9	122
13 " 6 "	113	13	126
14 " 0 "	113	17	130
14 " 6 "	113	21	134
15 " 0 "	113	25	138
15 " 6 "	113	30	143
16 " 0 "	113	34	147
16 " 6 "	113	38	151
17 " 0 "	113	42	155
17 " 6 "	113	46	159
18 " 0 "	113	50	163
18 " 6 "	113	55	168
19 " 0 "	113	59	172
19 " 6 "	113	63	176
20 " 0 "	113	67	180
20 " 6 "	113	71	184
21 " 0 "	113	76	189
21 " 6 "	113	80	193
22 " 0 "	113	84	197
22 " 6 "	113	88	201
23 " 0 "	113	92	205
23 " 6 "	113	97	210

TABLE OF 9-INCH KEY BRICK

Continued

Inside Diameter	No. 1 Key	Straight	Total
24 ft. 0 in.	113	101	214
24 " 6 "	113	105	218
25 " 0 "	113	109	222
25 " 6 "	113	113	226
26 " 0 "	113	117	230
26 " 6 "	113	122	235
27 " 0 "	113	126	239
27 " 6 "	113	130	243
28 " 0 "	113	134	247
28 " 6 "	113	138	251
29 " 0 "	113	143	256
29 " 6 "	113	147	260
30 " 0 "	113	151	264
30 " 6 "	113	155	268
31 " 0 "	113	159	272
31 " 6 "	113	163	276
32 " 0 "	113	168	281
32 " 6 "	113	172	285
33 " 0 "	113	176	289
33 " 6 "	113	180	293
34 " 0 "	113	184	297
34 " 6 "	113	189	302
35 " 0 "	113	193	306

TABLE FOR STANDARD CIRCLE BRICK

Inside Diameter	24-in. Circle	36-in. Circle	48-in. Circle	60-in. Circle	72-in. Circle	Total
2 ft. 0 in.	12					12
2 " 3 "	9	4				13
2 " 6 "	6	8				14
2 " 9 "	3	12				15
3 " 0 "		16				16
3 " 3 "		11	6			17
3 " 6 "		7	11			18
3 " 9 "		3	16			19
4 " 0 "			20			20
4 " 3 "			14	7		21
4 " 6 "			9	13		22
4 " 9 "			4	19		23
5 " 0 "				24		24
5 " 3 "				17	8	25
5 " 6 "				11	15	26
5 " 9 "				5	22	27
6 " 0 "					28	28

Circle brick are also furnished for 96, 108 and 120 inside diameters.

All diameters are furnished 2½" thick by 4½" or 6" wide, and 9" back.

Splits 1¼" thick furnished in above sizes.

TABLE FOR CIRCLE BRICK

For Length of Chord Multiply Sine by Diameter

No. to Circle	Sine of Half Angle	Diameter for 9″ Chord	No. to Circle	Sine of Half Angle	Diameter for 9″ Chord
5	.58779	15.311″	28	.11196	80.385″
6	.50000	18.000″	29	.10811	83.248″
7	.43386	20.740″	30	.10453	86.099″
8	.38268	23.518″	31	.10044	89.605″
9	.34202	26.314″	32	.09802	91.818″
10	.30902	29.124″	33	.09507	94.667″
11	.28173	31.945″	34	.09225	97.560
12	.25882	34.773″	35	.08965	100.390
13	.23932	37.606″	36	.08716	103.257″
14	.22251	40.447″	37	.08481	106.119″
15	.20791	43.287″	38	.08258	108.985″
16	.19509	46.132″	39	.08046	111.856″
17	.18428	48.833″	40	.07846	114.708″
18	.17365	51.828″	41	.07655	117.570″
19	.16459	54.681″	42	.07472	120.449″
20	.15643	57.533″	43	.07300	123.287″
21	.14904	60.386″	44	.07136	127.102″
22	.14230	63.246″	45	.06976	129.014″
23	.13617	66.094″	46	.06825	131.868″
24	.13053	68.949″	47	.06679	134.750″
25	.12534	71.805″	48	.06540	137.614″
26	.12054	74.664″	49	.06407	140.471″
27	.11609	77.526″	50	.06279	143.334″

TABLE OF 13½-INCH KEY BRICK

Inside Diameter	No. 2 Key	No. 1 Key	Straight	Total
6 ft. 0 in.	52			52
6 " 6 "	48	7		55
7 " 0 "	42	16		58
7 " 6 "	37	24		61
8 " 0 "	33	32		65
8 " 6 "	28	40		68
9 " 0 "	23	48		71
9 " 6 "	18	56		74
10 " 0 "	12	65		77
10 " 6 "	7	73		80
11 " 0 "	2	81		83
11 " 3 "		85		85
11 " 6 "		85	2	87
12 " 0 "		85	5	90
12 " 6 "		85	8	93
13 " 0 "		85	11	96
13 " 6 "		85	14	99
14 " 0 "		85	17	102
14 " 6 "		85	21	106
15 " 0 "		85	24	109
15 " 6 "		85	27	112
16 " 0 "		85	30	115
16 " 6 "		85	33	118

TABLE OF 13½-INCH KEY BRICK

Continued

Inside Diameter	No. 1 Key	Straight	Total
17 ft. 0 in	85	36	121
17 " 6 "	85	39	124
18 " 0 "	85	43	128
18 " 6 "	85	46	131
19 " 0 "	85	49	134
19 " 6 "	85	52	137
20 " 0 "	85	55	140
20 " 6 "	85	58	143
21 " 0 "	85	61	146
21 " 6 "	85	65	150
22 " 0 "	85	68	153
22 " 6 "	85	71	156
23 " 0 "	85	74	159
23 " 6 "	85	77	162
24 " 0 "	85	80	165
24 " 6 "	85	83	168
25 " 0 "	85	87	172
25 " 6 "	85	90	175
26 " 0 "	85	93	178
26 " 6 "	85	96	181
27 " 0 "	85	99	184
27 " 6 "	85	102	187
28 " 0 "	85	105	190

TABLE OF 13½-INCH KEY BRICK

Continued

Inside Diameter	No. 1 Key	Straight	Total
28 ft. 6 in.	85	109	194
29 " 0 "	85	112	197
29 " 6 "	85	115	200
30 " 0 "	85	118	203
30 " 6 "	85	121	206
31 " 0 "	85	124	209
31 " 6 "	85	127	212
32 " 0 "	85	131	216
32 " 6 "	85	134	219
33 " 0 "	85	137	222
33 " 6 "	85	140	225
34 " 0 "	85	143	228
34 " 6 "	85	146	231
35 " 0 "	85	149	234

TABLE OF 9 x 6 x 3-INCH KEY BRICK

Inside Diameter	No. 2 Key 9x(6-4 13/16) x3"	No. 1 Key 9x(6-5 3/8) x3"	Straight	Total
6 ft. 0 in.	47			47
6 " 6 "	44	6		50
7 " 0 "	42	12		54
7 " 6 "	38	19		57
8 " 0 "	34	26		60
8 " 6 "	31	32		63
9 " 0 "	27	39		66
9 " 6 "	23	46		69
10 " 0 "	20	52		72
10 " 6 "	16	59		75

TABLE OF 9 x 6 x 3-INCH KEY BRICK
Continued

Inside Diameter	No. 2 Key 9x(6-4 13/16) x3″	No. 1 Key 9x(6-5 3/8) x3″	Straight	Total
11 ft. 0 in.	13	66		79
11 " 6 "	10	72		82
12 " 0 "	6	79		85
12 " 6 "	3	85		88
13 " 0 "		91		91
13 " 6 "		91	3	94
14 " 0 "		91	6	97
14 " 6 "		91	10	101
15 " 0 "		91	13	104
15 " 6 "		91	16	107
16 " 0 "		91	19	110
16 " 6 "		91	22	113
17 " 0 "		91	25	116
17 " 6 "		91	28	119
18 " 0 "		91	32	123
18 " 6 "		91	35	126
19 " 0 "		91	38	129
19 " 6 "		91	41	132
20 " 0 "		91	44	135
20 " 6 "		91	47	138
21 " 0 "		91	50	141
21 " 6 "		91	54	145
22 " 0 "		91	57	148
22 " 6 "		91	60	151
23 " 0 "		91	63	154
23 " 6 "		91	66	157
24 " 0 "		91	69	160
24 " 6 "		91	72	163
25 " 0 "		91	76	167
25 " 6 "		91	79	170
26 " 0 "		91	82	173
26 " 6 "		91	85	176
27 " 0 "		91	88	179
27 " 6 "		91	91	182
28 " 0 "		91	94	185
28 " 6 "		91	98	189
29 " 0 "		91	101	192
29 " 6 "		91	104	195
30 " 0 "		91	107	198

TABLE OF GAS FLUE ARCH BRICK
FOR BLAST FURNACE DOWNCOMER

Inside Diameter Openings	Shapes Required			
	No. 3	No. 4	No. 5	Straight
2 ft. 9 in	46			
3 " 0 "	34	15		
3 " 6 "	16	38		
4 " 0 "		59		
4 " 6 "		26	39	
5 " 0 "			70	
5 " 6 "			70	6
6 " 0 "			70	11
6 " 6 "			70	16
7 " 0 "			70	22
7 " 6 "			70	27
8 " 0 "			70	32
8 " 6 "			70	38
9 " 0 "			70	43

CUPOLA BLOCKS

Inside Diameter Cupola Lining	Shapes Required			
	30-Inch	36-Inch	48-Inch	60-Inch
2 ft. 6 in	15			
2 " 9 "	8	8		
3 " 0 "		17		
3 " 3 "		12	6	
3 " 6 "		8	11	
3 " 9 "		4	16	
4 " 0 "			21	
4 " 3 "			15	7
4 " 6 "			10	13
4 " 9 "			5	19
5 " 0 "				25

NUMBER OF FIRE BRICK REQUIRED FOR ONE COURSE OF 4½-INCH THICK ARCH

SPAN	RISE 3″					6″					9″				12″				15″			
	No. 2 Arch	No. 1 Arch	Square	Radius	Length Arc	No. 2 Arch	No. 1 Arch	Square	Radius	Length Arc	No. 2 Arch	Square	Radius	Length Arc	No. 2 Arch	Square	Radius	Length Arc	No. 2 Arch	Square	Radius	Length Arc
				in.	in.				in.	in.			in.	in.			in	in			in.	in.
2′ 0″	10	2	...	25½	24¾	8	6	...	15	28	16	2	12½	32	...	...	...	...	...	...	...	...
2′ 6″	...	11	3	39	30¾	9	...	6	21¾	31	13	6	17	37	...	...	...	...	...	...	...	...
3′ 0″	...	...	...	...	...	...	16	2	30	39	11	9	22½	42	14	9	19½	46	...	...	...	...
3′ 6″	...	...	...	...	...	...	13	7	39¾	45	10	12	29	47	14	11	24⅜	51	...	...	...	...
4′ 0″	...	...	...	...	...	...	17	10	51	50	9	15	36½	53	13	13	30	56	13	15	26¾	60

SPAN	RISE	6″				8″				9″				10″				12″				15″				18″				20″				25″				30″			
		No. 1 Wedge	Square	Radius	Length of Arc	No. 1 Wedge	Square	Radius	Length of Arc	No. 1 Wedge	Square	Radius	Length of Arc	No. 1 Wedge	Square	Radius	Length of Arc	No. 1 Wedge	Square	Radius	Length of Arc	No. 1 Wedge	Square	Radius	Length of Arc	No. 1 Wedge	Square	Radius	Length of Arc	No. 1 Wedge	Square	Radius	Length of Arc	No. 1 Wedge	Square	Radius	Length of Arc	No. 1 Wedge	Square	Radius	Length of Arc
4′-6″		12	13	$63\frac{3}{4}$	$55\frac{3}{4}$					18	10	45	58	23	7	$36\frac{7}{8}$	61	28	5	32	65	34	2	$27\frac{7}{8}$	$68\frac{3}{4}$																
5′-0″						15	14	$60\frac{1}{4}$	$62\frac{3}{4}$					19	12	50	65	22	10	$43\frac{1}{2}$	67	25	9	$37\frac{1}{2}$	$69\frac{1}{2}$					34	5	$32\frac{1}{2}$	76								
5′-6″						14	17	72	69					18	15	$59\frac{1}{2}$	71	20	14	$51\frac{3}{8}$	73	26	11	$43\frac{3}{4}$	76					33	8	$37\frac{1}{4}$	81								
6′-0″						13	20	85	$74\frac{3}{8}$					15	19	$69\frac{1}{2}$	$75\frac{5}{8}$	18	18	60	78	23	15	$50\frac{3}{4}$	81					29	13	$42\frac{1}{2}$	87								
6′-6″						11	24	100	80					14	22	81	82	18	20	$69\frac{1}{2}$	84	22	18	$58\frac{1}{4}$	86					28	16	48	92								
7′-0″						10	27	114	86					14	24	$93\frac{1}{4}$	87	16	24	80	89	20	22	$66\frac{3}{8}$	92					28	18	$54\frac{1}{2}$	97								
7′-6″														13	28	106	94	15	27	91	96	19	25	75	98					24	23	$60\frac{1}{2}$	103	29	22	$52\frac{3}{4}$	109				
8′-0″														9	33	120	$98\frac{3}{4}$	14	30	102	101	18	28	84	103					23	26	$67\frac{1}{2}$	108	29	24	$58\frac{1}{2}$	114				
8′-6″														11	34	$135\frac{5}{8}$	105	14	32	114	106	18	30	$94\frac{1}{2}$	109					23	28	75	113	26	28	$64\frac{1}{2}$	119				
9′-0″														10	37	$150\frac{1}{2}$	111	13	35	$127\frac{1}{2}$	$111\frac{1}{2}$	16	34	$104\frac{5}{8}$	115					21	32	83	119	24	32	$70\frac{1}{2}$	125				
9′-6″														10	39	$167\frac{1}{2}$	$116\frac{1}{2}$	12	38	$141\frac{3}{8}$	$117\frac{3}{8}$	15	37	116	121					21	34	91	125	24	34	$77\frac{1}{2}$	130				
10′-0″																		11	41	156	$123\frac{3}{4}$	14	40	$127\frac{1}{2}$	127					19	38	100	131	23	37	85	136	26	36	75	139
10′-6″																		13	42	$171\frac{3}{8}$	129	14	42	140	132					18	41	109	136	23	39	91	141	26	38	$81\frac{1}{8}$	$144\frac{1}{2}$
11′-0″																		13	44	$187\frac{1}{2}$	$134\frac{1}{4}$	13	45	153	138					17	44	119	142	22	42	100	146	26	40	$87\frac{5}{8}$	$149\frac{1}{2}$

General Information About Fire Brick

All Fire Brick should be kept in a dry place.

Moisture, especially in cold weather, will greatly injure any brick.

To obtain the best results from brickwork, observe the following precautions:

Use good fire clay equal in refractoriness to the brick itself, mixing with water to thin paste. Dip brick and rub to make a brick to brick joint.

Warm slowly to expel moisture.

From 400 to 600 pounds of fire clay are enough to lay one thousand brick. Fine ground fire clay should be used for laying up fire-clay brick.

For estimating on fire brick work, use the following figures:

1 square foot 4½-inch wall requires 7 brick.

1 square foot 9-inch wall requires 14 brick.

1 square foot 13½-inch wall requires 21 brick.

1 cubic foot brick-work requires 17 nine-inch straight brick.

1 cubic foot fire clay brick-work weighs 150 pounds.

1,000 brick (closely stacked) occupy 56 cubic feet.

1,000 brick (loosely stacked) occupy 72 cubic feet.

When keys, wedges or other shapes are used in any considerable quantity, add 10% to the estimated number of squares for the total.

Red Brick work is estimated on basis of 21 brick per cubic foot.

For lime mortar figure on 9 cubic feet of clean, sharp sand—3 bushels lime per thousand brick.

This test, and the next two following (Pages 105 and 107), reprinted by courtesy of American Society for Testing Materials, Philadelphia, Pa., U. S. A., affiliated with the International Association for Testing Materials.

STANDARD TEST

For

REFRACTORY MATERIALS UNDER LOAD AT HIGH TEMPERATURES

Serial Designation: C-16-20

This test is issued under the fixed designation C 16; the final number indicates the year of original adoption as standard, or in the case of revision, the year of last revision.

Proposed as Tentative, 1917; Adopted in Amended Form, 1920.

Object

1. The object of this test is to determine the resistance of the specimen to deformation at a specified temperature for a specified time, when subjected to a compressive load of 25 lb. per sq. in. (1.765 kg. per sq. cm.).

Apparatus

2. The apparatus consists essentially of a furnace and loading device. It shall be constructed in accordance with Figs. 1 and 2.

(*a*) The furnace shall be cylindrical in form, 18 in. (457 mm.) in internal diameter, as shown in Fig. 1 (Plate II).

(*b*) The heating shall be done with gaseous or oil fuel and compressed air, using not less than two burners located tangentially and so arranged that no flame can impinge upon the test specimen. The burners shall be such as will insure a uniform temperature in all parts of the furnace and be under complete control.

(*c*) The method of loading shown in Fig. 1 shall be used, and the details shall be such as will insure accuracy in the applied load and freedom from eccentric loading, both in the original application and during the testing. It is advantageous to make the cross-beams as light as possible, so that the greater portion of the load may be concentrated in the weights.

TABLE I.—TEMPERATURE TO BE ATTAINED AT TIME SPECIFIED.

ALL TEMPERATURES IN DEGREES CENTIGRADE.

TIME	SILICA	FIRE CLAY		
		Heavy Duty	Moderate Duty	Light Duty
Hr. Min.				
15	40	160	160	160
30	80	280	280	280
45	140	400	400	400
1 0	200	500	500	500
15	260	620	595	570
30	290	720	685	640
45	300	815	770	700
2 0	310	900	850	755
15	320	980	920	810
30	385	1045	990	860
45	490	1100	1050	905
3 0	590	1150	1100	950
15	695	1195	1145	985
30	800	1235	1185	1020
45	900	1270	1220	1050
4 0	1000	1300	1250	1075
15	1100	1330	1275	1090
30	1200	1350	1300	1100
45	1250	1350	1300	1100
5 0	1300	1350	1300	1100
15	1350	1350	1300	1100
30	1380	1350	1300	1100
45	1410	1350	1300	1100
6 0	1440	1350 End	1300 End	1100 End
15	1470			
30	1500			
45	1500			
7 0	1500			
15	1500			
30	1500			
45	1500			
8 0	1500 End			

(*d*) The temperature may be measured either with a calibrated platinum-rhodium thermo-couple, encased in a double protecting tube with the junction not more than 1 in. (25 mm.) from the side or edge of the specimen and approximately opposite the center; or with some form of optical pyrometer that has been calibrated against a thermo-couple in the furnace. If the thermo-couple is used, the cold-end temperature should be kept constant in melted ice. A recording form of indicator is recommended where possible.

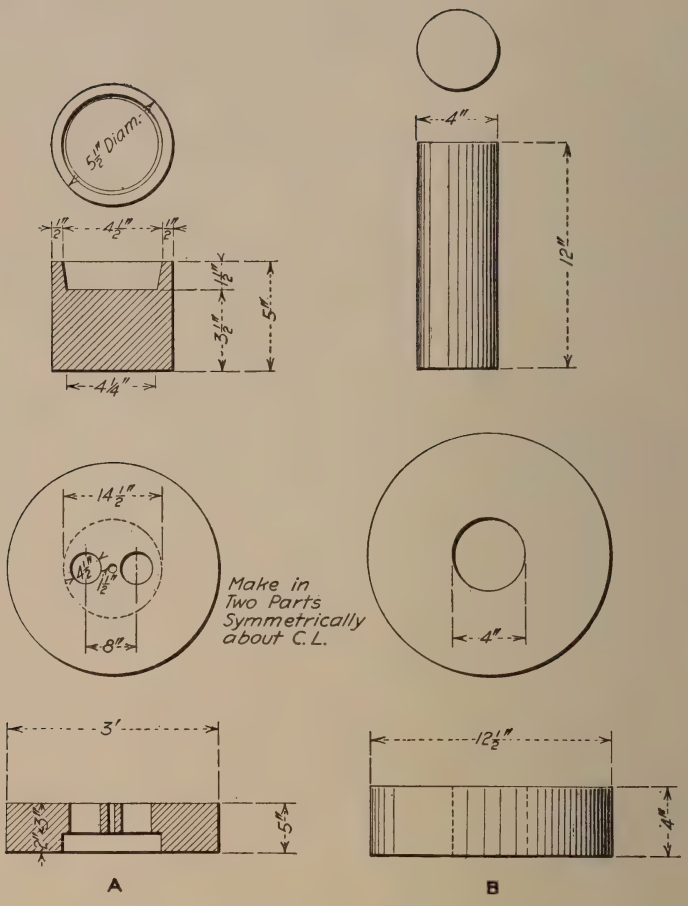


Fig. 2.—Special Shapes Required for Furnace.
—*By courtesy of Metallurgical and Chemical Engineering.*

Test Specimen

3. The test specimen shall consist, whenever possible, of a standard 9-in. brick placed vertically on end. In the case of blocks or shapes, sections approximately 9 by 4½ by 2½ in. (228 by 114 by 64 mm.) shall be cut, utilizing as far as possible existing plane surfaces. The ends of the specimen shall be either ground so that they are parallel and perpendicular to the vertical axis, or if this is impossible, shall be bedded in a neutral cement, so that the specimen is perpendicular to the base of the furnace.

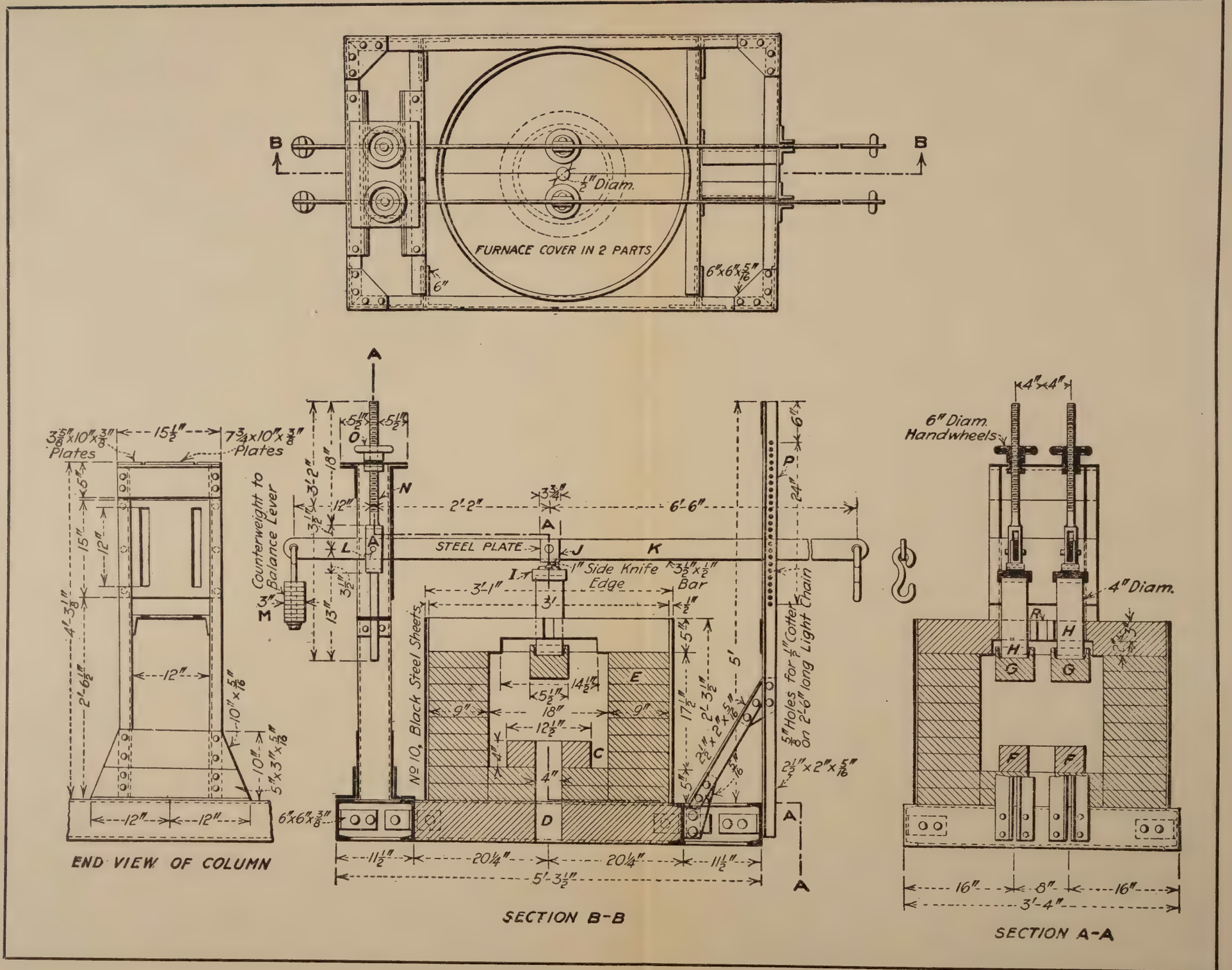


Fig. 1—Apparatus for Testing Refractory Materials under Load at High Temperatures.

(By courtesy of *Metallurgical and Chemical Engineering.*)



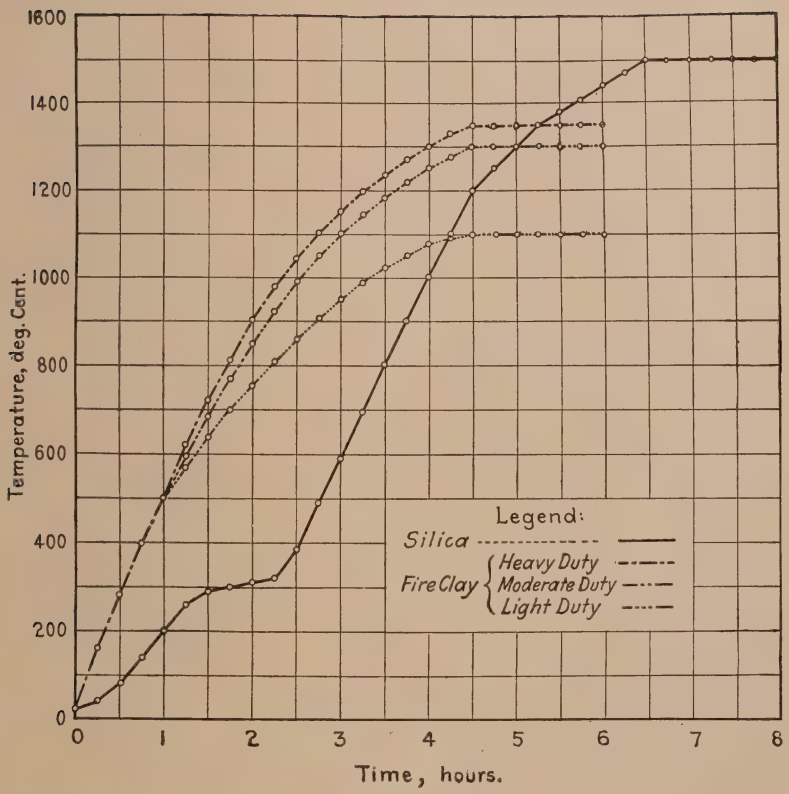


Fig. 3.—Time-Temperature Curve for Load Test.

The test specimen shall be measured before testing, making not less than five observations in each direction to within ±0.02 in. (0.5 mm.). The average dimensions shall be reported, and the cross-section calculated.

Starting the Test

4. The test specimen shall occupy approximately the center of the furnace and should rest on a block of some highly refractory material, having a minimum expansion or contraction. A silicon-carbide brick has been found satisfactory. At the top of the test specimen a block of similar highly refractory material should be placed, extending through the furnace top to receive the load.

NOTE—Gross errors which may more than double the contraction will result if the specimen is not set perpendicular to the base of the support or if the load is eccentrically applied.

Heating

5. The rate of heating shall be in accordance with the requirements of Table I and the time-temperature curves of Fig. 3, which give the rate and time of heating suggested for different grades of material.

Loading

6. (*a*) The load is calculated from the average cross-section as determined on the untested specimen and the requirement of the test. It is recommended that for general purposes, 25 lb. per sq. in. (1.765 kg. per sq. cm.) be used.

(*b*) The additional masses required to give the desired loading should be equally distributed on each side of the beam.

Completing the Test

7. (*a*) At the expiration of the time of heating, the supply of heat shall be stopped and the furnace allowed to cool, during not less than 5 hours before removing the load and examining the test specimen.

NOTE—The specimen shall be examined immediately after the heating is stopped for evidences of cracking and spalling, as such defects may develop later due to the rapid cooling of the furnace.

(*b*) After the test specimen has cooled to the room temperature, it shall be remeasured as before described, and the change in length recorded and reported as percentage of the original length.

NOTE.—It is recommended that a photograph be made of the specimen before and after testing, as yielding valuable information at a minimum time and expense.

STANDARD TEST
For
POROSITY AND PERMANENT VOLUME CHANGES IN REFRACTORY MATERIALS
Serial Designation: C 20-20

This test is issued under the fixed designation C 20; the final number indicates the year of original adoption as standard, or in the case of revision, the year of last revision.

Proposed as Tentative, 1918; Adopted, 1920.

Object

1. The object of this test is to determine the porosity and permanent volume changes in refractory materials when heated to series of specified temperatures.

Preparation of Test Specimens

2. (*a*) The sample shall consist of at least seven standard-size bricks.

(*b*) Test specimens measuring 2½ by 2½ by 1¼ in. shall be cut so as to remove the original surfaces of the bricks; for this a "cut-off" grinding wheel is recommended. There should be five test specimens for each of the seven heat treatments specified in Section 4 or 35 test specimens for each kind of brick. The test specimens shall be brushed or washed free from all adhering dust and marked serially with a refractory stain, for which 5 per cent cobalt-kaolin mixture is suggested.

Procedure

3. After the test specimens have been cut and cleaned, they shall be dried and the volumes and porosity of each obtained as described in Sections 5 and 6. They shall be heated as specified in Section 4, and the changes in volume and porosity determined.

Burning

4. (*a*) Dry the test pieces prior to placing in the kiln.

(*b*) Raise the temperature as rapidly as is consistent with even heat distribution to 1200° C. From 1200° C. raise the temperature at the rate of 30° per hour, drawing samples at each 50° interval from 1200 to 1500° C.

(*c*) If it is possible and the number of brands being tested warrant, it is best that separate burns to each temperature be made and the kiln sealed and allowed to cool by radiation. In case separate burns cannot be made, the five test specimens from each temperature increment should be covered with hot sand immediately on being drawn; or placed in a supplementary furnace and kept at about 500° C. until all drawings are completed, and then cooled with the furnace sealed to cool wholly by radiation.

Method of Obtaining Data

5. (*a*) The test specimens shall be cleaned from adhering or loosely attached pieces and particles, care being taken not to alter the exterior volume as originally prepared for this test.

(*b*) The test specimens shall be heated if necessary to 110° C. to remove moisture, and their dry weight (*D*) obtained to 0.10 g.

(*c*) The test specimens shall be placed in kerosene of known density (*S*) under a vacuum of 24 in. for 4 hours at 25° C. and cooled to room temperature while yet immersed.

(*d*) When cool, each test specimen shall be weighed suspended in kerosene at 25° C. to determine its *Suspended Weight* (*S*), in grams.

(*e*) The *Saturated Weight* (*W*), in grams, of each test specimen shall be obtained immediately after obtaining the suspended weight, by drying lightly with a kerosene-moistened towel to remove the excess kerosene and then weighing in air.

(*f*) The *Exterior Volume* (*V*), in cubic centimeters, of each test specimen is obtained by subtracting the suspended weight (*S*) from the saturated weight (*W*), and dividing by the density (δ) of the kerosene. Thus,

$$V = \frac{W - S}{\delta} \quad \ldots\ldots (1)$$

(*g*) The *Actual Volume of Open Pores* (V_1), in cubic centimeters, is obtained by subtracting the dry weight (*D*) from the saturated weight (*W*), and dividing by the density (δ) of the kerosene. Thus:

$$V_1 = \frac{W - D}{\delta} \quad \ldots\ldots (2)$$

(*h*) The *Apparent Specific Gravity* (T_1) of that portion of the test specimen which is impervious to liquid is obtained by dividing the dry weight by the difference between the dry and suspended weights, and multiplying by the density of the kerosene. Thus:

$$T_1 = \frac{D}{D - S}\delta \quad \ldots\ldots (3)$$

(*i*) The *True Specific Gravity* (*T*) of the wholly solid or burned clay portion is obtained by crushing a portion of the dried test specimen to 120-mesh powder and determining the displacement at 25° C. under 24 in. vacuum, of a 20-g. sample in a 50-cc. straight-wall pyknometer using kerosene, and correcting for density of the kerosene.

(*j*) The *Volume of Sealed Pores* (V_2), in cubic centimeters, is obtained by subtracting the quotient of dry weight (*D*) divided by true specific gravity (*T*) from the volume of the impervious portion of the test specimen; or

$$V_2 = \frac{(D - S)}{\delta} - \frac{D}{T} \quad \ldots\ldots (4)$$

(*k*) The *Volume Shrinkage* is obtained by subtracting the volumes, that is, the values of $\frac{W - S}{\delta}$, before and after the heat treatment.

Basis of Reference for the Data

6. To show progressive changes in the several volumes, refer all volumes back to the original exterior volume of the test specimen as 100. This is done by multiplying all volumes by the factor $100/V$, in which V is the exterior volume of the test specimen prior to the subjection to heat treatment.

The volume data should be determined for each test specimen and multiplied by the above factor to reduce all volumes for each test specimen to terms of 100 original exterior volumes of that test specimen before the average of the five for each heat treatment is calculated.

STANDARD TEST
For
SOFTENING POINT OF FIRE-CLAY BRICK
Serial Designation: C 24-20

This test is issued under the fixed designation C 24; the final number indicates the year of original adoption as standard, or in the case of revision, the year of last revision.

Proposed as Tentative, 1919; Adopted, 1920.

Object

1. The object of this test is to determine the softening point of fire-clay brick, by comparison of test cones with standard Orton pyrometric cones heated in a suitable furnace.

Preparation of Sample

2. A 1-kg. (2-lb.) sample shall be taken by chipping off approximately equal portions from the corners of the brick. These fragments shall be reduced in size by means of rolls or a jaw crusher adjusted to pass a lump 6 mm. (¼ in.) in diameter. They shall be mixed thoroughly, and the amount of material reduced to about 250 g. (5 lb.) by quartering. A magnet shall be repeatedly passed through the crushed material until all particles of metallic iron are removed. This portion shall be ground in a porcelain or agate mortar to pass a 60-mesh Standard sieve.[1] In order to avoid excessive reduction of the fines, they shall be removed frequently during the process of reduction by throwing the sample on the sieve and continuing the grinding of the coarser particles until all the sample will pass through the sieve.

Preparation of Test Cones

3. (*a*) The sample thus prepared shall be thoroughly mixed and after the addition of sufficient dextrine or glue and water, shall be formed into test cones in a metal mold in the shape of tetrahedrons, measuring 5 mm (3/16 in.) on the sides at the base and 25 mm. (1 in.) high.

[1] Diameter of wire 0.185 mm., opening 0.25 mm.

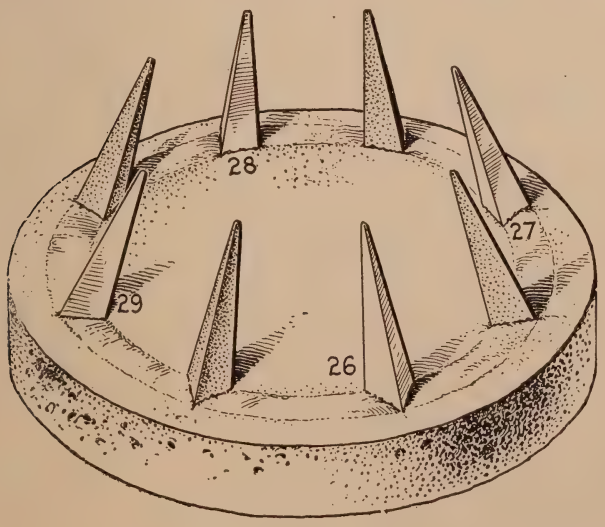


Fig. 1.

(*b*) When dry the test cones may be subjected to a preliminary burn at a temperature not exceeding 1300° C. (2372° F.) for the purpose of sintering them into a firm condition to permit handling.

Mounting

4. The test cones shall be mounted on plaques of refractory material of such a composition as will not affect the fusibility of the cones.[1] They shall be mounted with the base embedded approximately 1 mm. (0.04 in.) in the plaque and the face of one side inclined at an angle of 75 deg. with the horizontal. The arrangement with respect to the Orton cones shall be substantially as shown in Fig. 1, that is, alternating with the Orton cones in such a way that Orton cones of successive numbers will be placed opposite each other. The plaque may be any convenient size and shape and may be biscuited before using, if desired.

Heating

5. (*a*) The heating shall be done in a suitable furnace at a rate not greater than 15° C. (27° F.) per minute, nor less than 10° C. (18° F.) per minute after cone No. 1 is reached, or as nearly within these limits as possible.

(*b*) That type of furnace in which a neutral or oxidizing atmosphere may be maintained is to be preferred. Excessive reducing conditions should be avoided. Care should be taken that the flame does not strike directly against the cone or cone plaque. The furnace should be tested at intervals for the determination of the uniformity of the distribution of the heat.

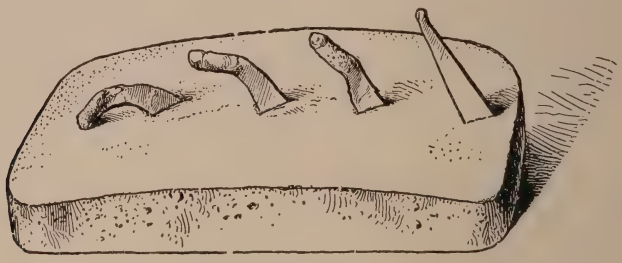


Fig. 2.

Softening Point

6. (*a*) The softening of the cone will be indicated by the top bending over and assuming the position shown in Fig. 2. The bloating, squatting or unequal fusion of small constituent particles should always be reported. The softening point shall be reported in terms of Orton cones and shall be that cone which most nearly corresponds in time of softening with the test cone. If the test cone softens later than one Orton cone but earlier than the next Orton cone and approximately midway between, the softening point shall be reported thus: Cone No. 31-32.

(*b*) If the test cone starts bending at an early cone but is not down until a later cone, the fact should be reported.

[1] A mixture of equal parts of a highly refractory clay, such as a good grade of china clay, and fused alumina which will pass a 100-mesh sieve, has been found satisfactory.

The 7-Pound Basis

In earlier days, the "soft-mud" method of making brick usually produced a coarse-grained, loose texture. A 9-inch straight (i. e., 9x4½x2½ inches) brick averaged 7 pounds weight, and by custom this became a standard. In figuring the size of tile and other shapes larger than a standard brick, to the equivalent of 9-inch brick, the weight of the larger piece was divided by seven.

As most 2½ x 4½ x 9 inch brick that are made by present day methods weigh more than 7 pounds, there is no advantage in adhering to this obsolete standard. For several years this Company has sold tile and special shapes by the ton, and the simplicity of this method and its convenience has won the hearty approval of our customers.

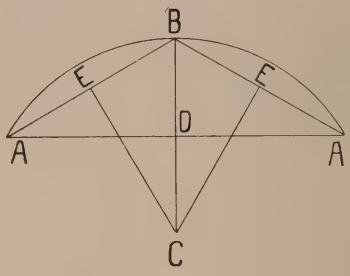
Rule for Finding the Radius of the Arc of Any Circle

Take one half the base line, square it, and to the product add the square of the rise; divide the sum by twice the rise; the quotient will be the radius of the circle.

Example—The base line of an arc is 20 feet; the rise is 5 feet—one half of 20 feet is 10 feet or 120 inches squared equals 14,400 inches—plus the square of 5 feet or 60 inches, 3,600, making 18,000 inches; divided by twice the rise, or 120 inches, equals 150 inches or 12 feet, 6 inches radius.

A Rule to Find the True Circle for Any Given Span and Rise

Draw line BC through the center and at right angles to the span or base line AA, making the distance D to B the height of the rise. Draw lines E from B to A, from the center of lines E draw lines at right angles which will meet on line BC at C, which is the center of the circle.



A Rule to Find the Inside Diameter of Any Circle by the Dimensions of a Brick

Rule—Double the length of the brick, as representing the thickness of the wall, multiply that product by the size of the brick at the small end, subtract from the size of the brick at the large end, the size of the brick at the small end, divide the product by the difference, and the quotient will be the size of the circle in inches.

This rule can be relied on in calculating Cupolas, Arches, Wedges and Keys of any length or breadth.

Example—What is the size circle that a key brick will turn, the sizes of which are 9 inches long, 4½ inches wide at large end and 4 inches wide at small end?

Solution:

9 inches, length brick
2

18

4½
4 inches, small end brick
4

½ or .5 | 72.0

144 inches or 12 feet diameter.

Colors Corresponding to Temperatures

(Pouillett, et al)

Orton Cone	Degree C. Approx.	
022	580	
021	650	Earliest visible Red
018	710	
015a	800	Dull Red
012a	865	
08a	940	Red
05a	1000	Cherry Red
01a	1080	Orange
4a	1155	
7	1230	Bright Orange, or Yellow
10	1300	
12-13	1370	Steel melts about 1350 C.
15-16	1445	Dazzling White
19	1515	
26-27	1590	Welding heat about 1540 C.

It must be remembered in using the above table that the figures are at best but rough approximations, as, when working on a large scale, **temperature is of less influence in causing contraction of clay, than the duration of exposure to heat**

—Searle: Clayworkers' Handbook

Weight of Coal

	Anthracite Per Cu. Ft.	Bituminous Per Cu. Ft.
Actual weight about.....	93.5 lbs.	About 84 lbs.
Broken (average).....	52 to 60 lbs.	47 to 56 lbs.
A Ton occupies.....	40 to 43 cu. ft.	43 to 48 cu. ft.

A ton of Coke occupies 80 to 97 cu. ft.

Coke swells in coking about 25 to 50%.

—Latta: American Gas Engineering Practice

Oil Tar

Two and six-tenths gallons of oil-tar (tar from which the water has been evaporated by means of steam coils) is equal to 1 bushel of coke as fuel under steam boilers. 6 gallons of tar equals 3 bushels of coal properly fired. It requires about 4 per cent of the steam generated to operate the atomizing oil spray for a boiler.

—Latta: American Gas Engineering Practice

Water

Pure water at 62° F. = 62.355 pounds per cubic foot or 8⅓ pounds per U. S. gallon. A cubic foot of water contains 7½ gallons.

30 pounds or 3.6 gallons of boiler feed water are required for each H. P. per hour.

1 gallon = 0.13368 cubic feet = 231 cubic inches.

1 pound of water = 27.681 cubic inches at 39.1° F.

To find the pressure of a column of water in pounds per square inch, multiply the height of the column in feet by .434.

Steam

Steam rising from water at its boiling point (212° F.) has a pressure equal to atmosphere (14.7 pounds per square inch).

TEMPERATURES

Below we give the temperatures of iron, steel and other metals, under various conditions, according to the latest scientific investigations.

	Centigrade Degrees	Fahrenheit Degrees
Tin melts	229	445
Lead melts	322	612
Lead boils	1040	1904
Zinc melts	412	775
Zinc boils	1040	1904
Aluminum melts	700	1252
Silver melts	957	1775
Brass melts	1021	1870
Copper melts	1029	1885
Gold melts	1038	1900
Cobalt melts	1100	2012
Cast Iron, white melts	1135	2075
Cast Iron, gray melts	1222	2230
Steel melts	1300	2372
Iron, wrought melts	1500	2732
Nickel melts	1500	2732
Platinum melts	2533	4593
Glass Furnace, between the pots ..	1375	2507
In the pots, refining	1310	2390
In the pots, working	1045	1913
Tanks melted for casting	1310	2390
Annealing Glassware	444 to 555	800 to 1000
Siemens Crucible Steel Furnace varies from	1460 to 1590	2660 to 2894

TEMPERATURES

Continued

	Centigrade Degrees	Fahrenheit Degrees
BESSEMER PROCESS		
Running the slag	1580	2876
Running steel into ladle	1640	2984
Running steel into mold	1580	2876
Soaking pit furnace, ingot in	1200	2192
Ingot under hammer	1080	1976
OPEN HEARTH PROCESS		
Gas from producers	720	1328
Gas entering generator	400	752
Gas leaving generator	1200	2192
Air leaving generator	1000	1832
Fumes passing to shaft	300	572
End of fusion of charge	1420	2588
Refining the steel	1500	2732
Running into ladle, first	1580	2876
Running into ladle, last	1490	2714
BLAST FURNACE Gray Bessemer		
Front of tuyere	1930	3506
At tapping	1570	2858
MAXIMUM FLAME TEMPERATURES		
Bunsen Burner, gas fully aerated	1871	3400
Bunsen Burner, insufficient air	1712	3134
Acetylene flame	2548	4618
Alcohol	1705	3101
Hydrogen—free flame and air	1900	3452
Oxy-Hydrogen blow pipe flame	2420	4388

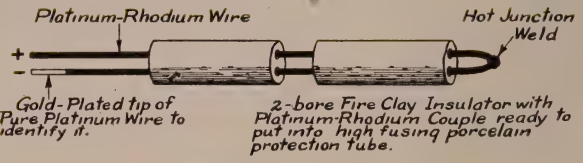
It must be understood that these temperatures cannot be obtained on a commercial scale from the flames mentioned. They are the temperatures of the hottest points in the flames, not that of the flame as a whole.—**Searle; Clay-workers' Hand Book.**

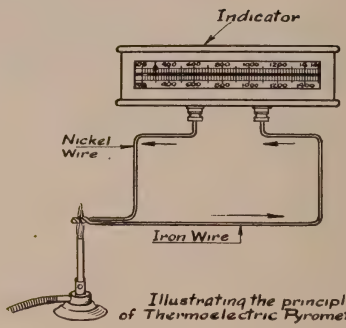
PYROMETERS

The Seger-Orton pyrometric cones for standardizing furnace and kiln temperatures and conditions, are means for eliminating guesswork. The cones are pyramid shaped, 1 to 1½ inches high, with approximately a ½-inch triangular base, and are compounds with known fusion points. They are used for regulating temperatures and conditions, rather than for accurate measurements. The indicated temperatures apply when the cone is affected sufficiently to cause the tip to bend over and touch the base.

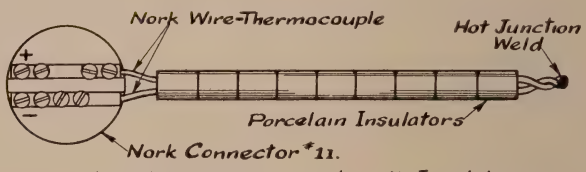
The Thermo-Electric Pyrometer operates on the principle that an electric current is generated when heat is applied to the coupling of two wires of dis-similar metals. The amount of current may be accurately measured by connecting the free ends of the wires, by means of copper lead wires, to an electrical indicating instrument, which is calibrated to read in terms of temperature instead of electrical units.

The thermo-couple may be made of an iron wire coupled with one of nickel, for instance, and such a device is called a "Base-metal" couple. The Walsh Plant is equipped with a Platinum and Platinum-Rhodium-alloy system, and each kiln is provided with a thermo-couple of these metals encased in a porcelain tube. The kiln is thus heated at the desired rate and is under close observation of the kiln foreman at all times.





Bunsen Burner heating wires connected with Indicator.



Nork Wire Thermocouple with Insulators and Connector ready to put in Protection Tube

Platinum-Alloy Thermo-Couple with insulating protection tube of porcelain.

—Courtesy of Wilson-Maeulen Co., New York

SEGER-ORTON CONES

Since the invention of the "Seger" pyrometric cones for measuring high temperatures by fusing substances with known fusion points, some of the standards that were used for this purpose have been corrected by the U. S. Bureau of Standards. The Bureau of Standards, therefore, has published a revised table of temperatures corresponding to these cones, and the revised list is printed together with Prof. E. Orton's list.

SOFTENING POINTS OF SEGER-ORTON CONES

Cone Numbers	According to Prof. E. Orton		According to Bureau of Standards	
	1094° F.	590° C.	1094° F.	590° C.
022	1148	620	1148	620
021	1202	650	1202	650
020	1256	680	1256	680
019	1310	710	1310	710
018	1364	740	1364	740
017	1418	770	1418	770
016	1472	800	1472	800
015	1526	830	1526	830
014	1580	860	1580	860
013	1634	890	1634	890
012	1688	920	1688	920
011	1742	950	1742	950
010	1778	970	1778	970
09	1814	990	1814	990
08	1850	1010	1850	1010
07	1886	1030	1886	1030
06	1922	1050	1922	1050
05	1958	1070	1958	1070
04	1994	1090	1994	1090
03	2030	1110	2030	1110
02	2066	1130	2066	1130
01				

SOFTENING POINTS OF SEGER-ORTON CONES

(Continued)

Cone Numbers	According to Prof. Orton		According to Bureau of Standards	
	2102° F.	1150° C.	2102° F.	1150° C.
1	2138	1170	2138	1170
2	2174	1190	2174	1190
3	2210	1210	2210	1210
4	2246	1230	2246	1230
5	2282	1250	2282	1250
6	2318	1270	2318	1270
7	2354	1290	2354	1290
8	2390	1310	2390	1310
9	2426	1330	2426	1330
10	2462	1350	2462	1350
11	2498	1370	2498	1370
12	2534	1390	2534	1390
13	2570	1410	2570	1410
14	2606	1430	2606	1430
15	2642	1450	2642	1450
16	2678	1470	2678	1470
17	2714	1490	2714	1490
18	2750	1510	2750	1510
19	2786	1530	2786	1530
20	2822	1550		
21	2858	1570		
22	2894	1590		
23	2930	1610		
24	2966	1630		
25	3002	1650	2912	1600
26	3038	1670	2948	1620
27	3074	1690	2975	1635
28	3110	1710	3002	1650
29	3146	1730	3038	1670
30	3182	1750	3065	1685
31	3218	1770	3101	1705
32	3254	1790	3128	1720
33	3290	1810	3164	1740
34	3326	1830	3200	1760
35	3362	1850	3236	1780
36	3398	1870	3272	1800
37	3434	1890	3308	1820
38	3470	1910	3344	1840
39	3506	1930	3380	1860
40				

Fusion Tests The American Society for Testing Materials has adopted a series of tests for determining, approximately, the quality of fire-brick.[1] These tests are helpful, and will doubtless lead to greater developments, but as they have not yet been closely co-ordinated with actual manufacturing conditions, the inexperienced investigator is likely to reach untrustworthy conclusions. Therefore, tests that are made by the Ceramic Departments of several universities,[2] by Mellon Institute of Industrial Research, Pittsburgh, Pa., or by the U. S. Bureau of Standards, Washington, D. C., are more dependable because of their more accurate interpretation with relation to practical operations.

Boiler H. P. A boiler horse-power is equivalent to the evaporation of 34.5 pounds of water per hour from and at 212° F. The rated horse-power, or the "Builder's rating," is the number of square feet of heating surface in the boiler divided, in the case of stationary boilers by ten or twelve, which after years of practice have been accepted as the heating surface equivalent to one horse-power. Ten is the more commonly used standard. (U. S. Fuel Administration, Bul. No. 1.)

(To ascertain heating surface in tubular boilers, multiply two-thirds of the circumference of the boiler by length of boiler in inches, and add to it the area of all the tubes.)

[1] See pages 100-108, inclusive.

[2] Ohio State University, Columbus, Ohio; Cornell University, Ithaca, N. Y.; University of Illinois, Champaign, Ill.; Iowa State College, Ames, Iowa; Rutgers College, New Brunswick, N. J. among others.

Approximate Total Heat of Combustion of One Pound of Fuel

Figures in the last two columns for amount of air required, are the minimum, and in practice twice or more times these amounts must be employed. Thus, ordinary coal usually needs 18 to 25 pounds of air per pound of coal in actual practice.

	B. T. U.	Equivalent evaporation of water from and at 212° F. per pound of fuel—POUNDS	Air chemically consumed per pound of fuel—Cu. Ft. at 62° F.—POUNDS	
Coal (average)	14,000	15¼	11	140
Coke	13,500	14	11	142
Dried Wood	11,000	11	4½	60
Peat, dried	12,000	12	7½	100
Petroleum	27,000	28	15	200

—*Searle: Clayworkers' Hand Book*

Radiation Losses of Heat Through Brick Wall

These figures are not exact, but are a fair average of radiation losses of heat through a brick wall. They show approximate losses per hour for each square foot of surface and for each degree (Fahrenheit) of difference in temperature between the two sides of the wall.

4½-inch Wall	0.45 B. T. U. per hour
9 -inch Wall	.36 B. T. U. per hour
13½-inch Wall	.28 B. T. U. per hour
18 -inch Wall	.25 B. T. U. per hour
Window Glass	.75 B. T. U. per hour

—*Searle: Clayworkers' Hand Book*

NOTE—Insulation of furnace walls and roofs to save radiation losses is not always good practice. A fire-brick with one cool side or end will last much longer than one that is subjected to intense heat on all sides. Hence, the expense of loss of heat by radiation must be figured by comparison with the expense of more rapid deterioration of the brick-work when insulated.

Weight of Air One cubic foot of air weighs 0.0803 pounds. One pound of air is equivalent to 12.4 cubic feet at pressure of one atmosphere (14.7 pounds per square inch) and at 32 ° F.

Heat Units A **Calorie,** the French unit for measuring heat, is the quantity of heat required to raise the temperature of 1 kilogram (2.2 pounds) of pure water 1° Centigrade (1.8° F.) at or near 4° C. (39.1° F.).

A **British Thermal Unit** (B. T. U.) is the quantity of heat required to raise the temperature of one pound of pure water 1° F. at or near 39.1° F.

One B. T. U., therefore, is equivalent to 0.252 calories, and one calorie equals 3.968 B. T. U.

The starting temperature of the water is placed at 4° C. because water is at its maximum density at that temperature. A pound of fuel is the unit for measuring calorific value in B. T. U.

Specific Heat The relative quantity of heat required to raise the temperature of a substance 1° F., by comparison with the heat required to raise the same weight of water 1° (from 39.1° F.) is termed the Specific Heat of that substance.

USEFUL FACTS

To find circumference of a circle multiply diameter by 3.1416. To find diameter of a circle multiply circumference by .31831.

To find area of a circle multiply square of diameter by .7854.

To find area of a triangle multiply base by one-half perpendicular height.

To find surface of a ball multiply square of diameter by 3.1416.

To find side of an equal square multiply diameter by .8862.

To find cubic inches in a ball multiply cube of diameter by .5236.

Doubling the diameter of a pipe increases its capacity four times.

To find capacity of tanks any size: Given dimensions of a cylinder in inches, to find its capacity in U. S. gallons—Square the diameter, multiply by the length and by .0034.

OUT OF THE EARTH

Ask a friend what the fourth most valuable American mineral product is in terms of total production. Ask him where gold stands. Then show him this 1920 table, which surprises most people:

Coal (soft)	$1,950,000,000	Stone	$120,500,000
Iron (pig)	1,137,926,000	Lead (refined)	76,296,000
Petroleum	1,360,000,000	Sand	62,694,000
Clay products	364,220,000	Silver	57,420,000
Copper	222,467,000	Gold	49,509,000

The saying that our wealth comes out of the earth is well known, but it is little understood.

—Collier's Weekly

COMPARISON OF CENTIGRADE AND FAHRENHEIT THERMOMETERS

Centigrade	Fahrenheit	Centigrade	Fahrenheit	Centigrade	Fahrenheit
1815	3299	1770	3218	1725	3137
1814	3297.2	1769	3216.2	1724	3135.2
1813	3295.4	1768	3214.4	1723	3133.4
1812	3293.6	1767	3112.6	1722	3131.6
1811	3291.8	1766	3210.8	1721	3129.8
1810	3290	1765	3209	1720	3128
1809	3288.2	1764	3207.2	1719	3126.2
1808	3286.4	1763	3205.4	1718	3124.4
1807	3284.6	1762	3203.6	1717	3122.6
1806	3282.8	1761	3201.8	1716	3120.8
1805	3281	1760	3200	1715	3119
1804	3279.2	1759	3198.2	1714	3117.2
1803	3277.4	1758	3196.4	1713	3115.4
1802	3275.6	1757	3194.6	1712	3113.6
1801	3273.8	1756	3192.8	1711	3111.8
1800	3272	1755	3191	1710	3110
1799	3270.2	1754	3189.2	1709	3108.2
1798	3268.4	1753	3187.4	1708	3106.4
1797	3266.6	1752	3185.6	1707	3104.6
1796	3264.8	1751	3183.8	1706	3102.8
1795	3263	1750	3182	1705	3101
1794	3261.2	1749	3180.2	1704	3099.2
1793	3259.4	1748	3178.4	1703	3097.4
1792	3257.6	1747	3176.6	1702	3095.6
1791	3255.8	1746	3174.8	1701	3093.8
1790	3254	1745	3173	1700	3092
1789	3252.2	1744	3171.2	1699	3090.2
1788	3250.4	1743	3169.4	1698	3088.4
1787	3248.6	1742	3167.6	1697	3086.6
1786	3246.8	1741	3165.8	1696	3084.8
1785	3245	1740	3164	1695	3083
1784	3243.2	1739	3162.2	1694	3081.2
1783	3241.4	1738	3160.4	1693	3079.4
1782	3239.6	1737	3158.6	1692	3077.6
1781	3237.8	1736	3156.8	1691	3075.8
1780	3236	1735	3155	1690	3074
1779	3234.2	1734	3153.2	1689	3072.2
1778	3232.4	1733	3151.4	1688	3070.4
1777	3230.6	1732	3149.6	1687	3068.6
1776	3228.8	1731	3147.8	1686	3066.8
1775	3227	1730	3146	1685	3065
1774	3225.2	1729	3144.2	1684	3063.2
1773	3223.4	1728	3142.4	1683	3061.4
1772	3221.6	1727	3140.6	1682	3059.6
1771	3219.8	1726	3138.8	1681	3057.8

COMPARISON OF CENTIGRADE AND FAHRENHEIT THERMOMETERS

Continued

Centigrade	Fahrenheit	Centigrade	Fahrenheit	Centigrade	Fahrenheit
1680	3056	1635	2975	1590	2894
1679	3054.2	1634	2973.2	1589	2892.2
1678	3052.4	1633	2971.4	1588	2890.4
1677	3050.6	1632	2969.6	1587	2888.6
1676	3048.8	1631	2967.8	1586	2886.8
1675	3047	1630	2966	1585	2885
1674	3045.2	1629	2964.2	1584	2883.2
1673	3043.4	1628	2962.4	1583	2881.4
1672	3041.6	1627	2960.6	1582	2879.6
1671	3039.8	1626	2958.8	1581	2877.8
1670	3038	1625	2957	1580	2876
1669	3036.2	1624	2955.2	1579	2874.2
1668	3034.4	1623	2953.4	1578	2872.4
1667	3032.6	1622	2951.6	1577	2870.6
1666	3030.8	1621	2949.8	1576	2868.8
1665	3029	1620	2948	1575	2867
1664	3027.2	1619	2946.2	1574	2865.2
1663	3025.4	1618	2944.4	1573	2863.4
1662	3023.6	1617	2942.6	1572	2861.6
1661	3021.8	1616	2940.8	1571	2859.8
1660	3020	1615	2939	1570	2858
1659	3018.2	1614	2937.2	1569	2856.2
1658	3016.4	1613	2935.4	1568	2854.4
1657	3014.6	1612	2933.6	1567	2852.6
1656	3012.8	1611	2931.8	1566	2850.8
1655	3011	1610	2930	1565	2849
1654	3009.2	1609	2928.2	1564	2847.2
1653	3007.4	1608	2926.4	1563	2845.4
1652	3005.6	1607	2924.6	1562	2843.6
1651	3003.8	1606	2922.8	1561	2841.8
1650	3002	1605	2921	1560	2840
1649	3000.2	1604	2919.2	1559	2838.2
1648	2998.4	1603	2917.4	1558	2836.4
1647	2996.6	1602	2915.6	1557	2834.6
1646	2994.8	1601	2913.8	1556	2832.8
1645	2993	1600	2912	1555	2831
1644	2991.2	1599	2910.2	1554	2829.2
1643	2989.4	1598	2908.4	1553	2827.4
1642	2987.6	1597	2906.6	1552	2825.6
1641	2985.8	1596	2904.8	1551	2823.8
1640	2984	1595	2903	1550	2822
1639	2982.2	1594	2901.2	1549	2820.2
1638	2980.4	1593	2899.4	1548	2818.4
1637	2978.6	1592	2897.6	1547	2816.6
1636	2976.8	1591	2895.8	1546	2814.8

COMPARISON OF CENTRIGRADE AND FAHRENHEIT THERMOMETERS

Continued

Centi-grade	Fahren-heit	Centi-grade	Fahren-heit	Centi-grade	Fahren-heit
1545	2813	1500	2732	1455	2651
1544	2811.2	1499	2730.2	1454	2649.2
1543	2809.4	1498	2728.4	1453	2647.4
1542	2807.6	1497	2726.6	1452	2645.6
1541	2805.8	1496	2724.8	1451	2643.8
1540	2804	1495	2723	1450	2642
1539	2802.2	1494	2721.2	1449	2640.2
1538	2800.4	1493	2719.4	1448	2638.4
1537	2798.6	1492	2717.6	1447	2636.6
1536	2796.8	1491	2715.8	1446	2634.8
1535	2795	1490	2714	1445	2633
1534	2793.2	1489	2712.2	1444	2631.2
1533	2791.4	1488	2710.4	1443	2629.4
1532	2789.6	1487	2708.6	1442	2627.6
1531	2787.8	1486	2706.8	1441	2625.8
1530	2785	1485	2705	1440	2624
1529	2784.2	1484	2703.2	1439	2622.2
1528	2782.4	1483	2701.4	1438	2620.4
1527	2780.6	1482	2699.6	1437	2618.6
1526	2778.8	1481	2697.8	1436	2616.8
1525	2777	1480	2696	1435	2615
1524	2775.2	1479	2694.2	1434	2613.2
1523	2773.4	1478	2692.4	1433	2611.4
1522	2771.6	1477	2690.6	1432	2609.6
1521	2769.8	1476	2688.8	1431	2607.8
1520	2768	1475	2687	1430	2606
1519	2766.2	1474	2685.2	1429	2604.2
1518	2764.4	1473	2683.4	1428	2602.4
1517	2762.6	1472	2681.6	1427	2600.6
1516	2760.8	1471	2679.8	1426	2598.8
1515	2759	1470	2678	1425	2597
1514	2757.2	1469	2676.2	1424	2595.2
1513	2755.4	1468	2674.4	1423	2593.4
1512	2753.6	1467	2672.6	1422	2591.6
1511	2751.8	1466	2670.8	1421	2589.8
1510	2750	1465	2669	1420	2588
1509	2748.2	1464	2667.2	1419	2586.2
1508	2746.4	1463	2665.4	1418	2584.4
1507	2744.6	1462	2663.6	1417	2582.6
1506	2742.8	1461	2661.8	1416	2580.8
1505	2741	1460	2660	1415	2579
1504	2739.2	1459	2658.2	1414	2577.2
1503	2737.4	1458	2656.4	1413	2575.4
1502	2735.6	1457	2654.6	1412	2573.6
1501	2733.8	1456	2652.8	1411	2571.8

COMPARISON OF CENTIGRADE AND FAHRENHEIT THERMOMETERS

Continued

Centi-grade	Fahren-heit	Centi-grade	Fahren-heit	Centi-grade	Fahren-heit
1410	2570	1320	2408	870	1598
1409	2568.2	1310	2390	860	1580
1408	2566.4	1300	2372	850	1562
1407	2564.6	1290	2354	840	1544
1406	2562.8	1280	2336	830	1526
1405	2561	1270	2318	820	1508
1404	2559.2	1260	2300	810	1490
1403	2557.4	1250	2282	800	1472
1402	2555.6	1240	2264	790	1454
1401	2553.8	1230	2246	780	1436
1400	2552	1220	2228	770	1418
1399	2550.2	1210	2210	760	1400
1398	2548.4	1200	2192	750	1382
1397	2546.6	1190	2174	740	1364
1396	2544.8	1180	2156	730	1346
1395	2543	1170	2138	720	1328
1394	2541.2	1160	2120	710	1310
1393	2539.4	1150	2102	700	1292
1392	2537.6	1140	2084	690	1274
1391	2535.8	1130	2066	680	1256
1390	2534	1120	2048	670	1238
1389	2532.2	1110	2030	660	1220
1388	2530.4	1100	2012	650	1202
1387	2528.6	1090	1994	640	1184
1386	2526.8	1080	1976	630	1166
1385	2525	1070	1958	620	1148
1384	2523.2	1060	1940	610	1130
1383	2521.4	1050	1922	600	1112
1382	2519.6	1040	1904	590	1094
1381	2517.8	1030	1886	580	1076
1380	2516	1020	1868	570	1058
1379	2514.2	1010	1850	560	1040
1378	2512.4	1000	1832	550	1022
1377	2510.6	990	1814	540	1004
1376	2508.8	980	1796	530	986
1375	2507	970	1778	520	968
1374	2505.2	960	1760	510	950
1373	2503.4	950	1742	500	932
1372	2501.6	940	1724	490	914
1371	2499.8	930	1706	480	896
1370	2498	920	1688	470	878
1360	2480	910	1670	460	860
1350	2462	900	1652	450	842
1340	2444	890	1634	440	824
1330	2426	880	1616	430	806

COMPARISON OF CENTIGRADE AND FAHRENHEIT THERMOMETERS

Continued

Centigrade	Fahrenheit	Centigrade	Fahrenheit	Centigrade	Fahrenheit
420	788	220	428	20	68
410	770	210	410	10	50
400	752	200	392	0	32
390	734	190	374	1	30.2
380	716	180	356	2	28.4
370	698	170	338	3	26.6
360	680	160	320	4	24.8
350	662	150	302	5	23
340	644	140	284	6	21.2
330	626	130	266	7	19.4
320	608	120	248	8	17.6
310	590	110	230	9	15.8
300	572	100	212	10	14
290	554	90	194	11	12.2
280	536	80	176	12	10.4
270	518	70	158	13	8.6
260	500	60	140	14	6.8
250	482	50	122	15	5
240	464	40	104	16	3.2
230	446	30	86	17	1.4
				18	0.4

Zero in Centigrade is the freezing point of water.

To change degrees Centigrade to Fahrenheit, multiply by 9, divide by 5 and add 32.

To change degrees Fahrenheit to Centigrade, subtract 32, divide by 9 and multiply by 5.

EQUIVALENT VALUES OF ELECTRICAL AND MECHANICAL UNITS

(H. Ward Leonard in "The Electrical Engineer," February 25, 1895. Revised November, 1907.)

From "Manual for Engineers", Copyrighted by Charles E. Ferris, B. S.

Unit	Equivalent Value in Other Units
1 Watt.	1. joule per second. .00134 H.-P. 3,412 heat-units per hour. .7373 ft.-lb. per second. .0035 lb. water evap. per hour from and at 212° F. 44.24 ft.-lbs. per minute. 1 lb. pull at half a mile per hour. (approx.)
1 Watt per sq. in.	8.19 heat-units per sq. ft. per minute. 6371. ft.-lbs. per sq. ft. per minute. .193 H.-P. per sq. ft.
1 Heat Unit	1.055 watt seconds. 778. ft.-lbs. 107.6 kilogram meters. .000293 K. W. hour. .000393 H. P. hour. .0000688 lb. carbon oxidized. .001036 lb. water evap. from and at 212° F.
1 Heat-Unit per sq. ft. per min.	.122 watts per sq. in. .0176 K. W. per sq. ft. .0236 H. P. per sq. ft.
1 Kilogram Meter.	7.233 ft.-lbs. .00000365 H.-P. hour. .00000272 K. W. hour. .0093 heat-unit.
1 Lb. Carbon Oxidized With Perfect Efficiency.	14.544 heat-units. 1.11 lbs. anthracite coal oxidized. 2.5 lbs. dry wood oxidized. 21. cu. ft. illuminating gas. 4.26 K. W. hours. 5.71 H.-P. hours. 11,315,000 ft.-lbs. 15. lbs. of water evap. from and at 212° F.
1 Lb. Water Evap. from and at 212° F.	.283 K. W. hours. .379 H.-P. hour. 965.7 heat-units. 103,900 kg. m. 1,019,000 joules. 751,300 ft.-lbs. .0664 lb. carbon oxidized.

EQUIVALENT VALUES OF ELECTRICAL AND MECHANICAL UNITS

(H. Ward Leonard in "The Electrical Engineer," February 25, 1895. Revised November, 1907.)

From "Manual for Engineers," Copyrighted by Charles E. Ferris, B. S.

Unit	Equivalent Value in Other Units
1 K. W. Hour	1,000. watt hours. 1.34 H.-P. hours. 2,654,200 ft.-lbs. 3,600,000. joules. 3,412. heat-units. 367,000. kilogram meters. .235 lb. carbon oxidized with perfect efficiency. 3.53 lbs. water evap. from and at 212° F. 22.75 lbs. of water raised from 62° to 212° F.
1 H.-P. Hour	.746 K. W. hours. 1,930,000. ft.-lbs. 2.545. heat-units. 273.740 kg. m. .175 lbs. carbon oxidized with perfect efficiency. 2.64 lbs. water evap. from and at 212° F. 17.0 lbs. water raised from 62° F. to 212° F.
1 Kilo-Watt	1,000 watts. 1.34 H.-P. 2,654,200 ft.-lbs. per hour. 44,240. ft.-lbs. per minute. 737.3 ft.-lbs. per second. 3,412. heat-units per hour. 56.9 heat-units per minute. .948 heat-units per second. .2275 lbs. carbon oxidized per hour. 3.53 lbs. water evap. per hour from and at 212° F.
1 H.-P.	746. watts. .746 K. W. 33000. ft.-lbs. per minute. 550. ft.-lbs. per second. 2,545. heat-units per hour. 42.4 heat-units per minute. 707 heat-units per second. .175 lbs. carbon oxidized per hour. 2.64 lbs. of water evap. per hour from and at 212° F.
1 Joule	1 watt second. .000000278 K. W. hour. .102 kg. m. .0009477 heat-units. .7373 ft.-lb.
1 Ft.-Lb.	.1356 joules. 1.3883 kg. m. .000000377 K. W. hours. .001285 heat-units. .0000005 H.-P. hour.

COMPARISONS OF FUEL OIL AND COAL

RELATIVE BOILER EFFICIENCIES AND FUEL CONSUMPTION. A useful table calculated by C. C. Moore and Company, Engineers, and published in the "Mehanical Engineers' Hand-Book" (McGraw-Hill) gives a means of determining the relative consumption of coal and oil with different boiler efficiencies. This assumes the heating value of fuel oil at 18,500 B. T. U. per pound.

Gross Boiler Efficiency (Oil) Per Cent	Net Boiler Efficiency (Oil) Per Cent	Net Evaporated Lbs. Water Per Lb. Oil At 212° F	Water Evaporated at and From 212° F per Pound Coal			
			5	6	7	8
			Pounds of Oil Equal to One Pound of Coal			
73	71	13.54	0.3693	0.4431	0.5170	0.5909
74	72	13.73	0.3642	0.4370	0.5099	0.5827
75	73	13.92	0.3592	0.4310	0.5029	0.5747
76	74	14.11	0.3544	0.4253	0.4961	0.5670
77	75	14.30	0.3497	0.4196	0.4895	0.5594
78	76	14.49	0.3451	0.4141	0.4831	0.5521
79	77	14.68	0.3406	0.4087	0.4768	0.5450
80	78	14.87	0.3363	0.4035	0.4708	0.5380
81	79	15.06	0.3320	0.3984	0.4648	0.5312
82	80	15.25	0.3279	0.3934	0.4590	0.5246
83	81	15.44	0.3238	0.3886	0.4534	0.5181

Gross Boiler Efficiency (Oil) Per Cent	Net Boiler Efficiency (Oil) Per Cent	Net Evaporated Lbs. Water Per Lb. Oil At 212° F	Water Evaporated at and From 212° F per Pound Coal			
			9	10	11	12
			Pounds of Oil Equal to One Pound of Coal			
73	71	13.54	0.6647	0.7386	0.8124	0.8863
74	72	13.73	0.6556	0.7283	0.8011	0.8740
75	73	13.92	0.6466	0.7184	0.7903	0.8621
76	74	14.11	0.6378	0.7087	0.7796	0.8505
77	75	14.30	0.6294	0.6993	0.7692	0.8392
78	76	14.49	0.6211	0.6901	0.7591	0.8281
79	77	14.68	0.6131	0.6812	0.7493	0.8174
80	78	14.87	0.6053	0.6725	0.7398	0.8070
81	79	15.06	0.5976	0.6640	0.7304	0.7968
82	80	15.25	0.5902	0.6557	0.7213	0.7869
83	81	15.44	0.5829	0.6447	0.7125	0.7772

In the above table, the "Net Efficiency" is equal to the "Gross Efficiency" minus 2 per cent, or the steam consumption of 2 per cent taken from the gross efficiency gives the net efficiency.

COMPARISONS OF FUEL OIL AND COAL

Continued

Boiler tests have often given a gross efficiency of 83 per cent when using oil fuel but this is rather a high figure to expect under service conditions or with boilers not especially constructed for the use of oil. With efficient burners, furnace, and careful management there is no reason why a gross efficiency of 80 per cent ,or 14.87 pounds of water per pound of oil, could not be maintained, and 78 per cent might be considered good work. With re-converted coal furnaces, 75 to 76 per cent will probably be the expected range for good operations.

Ernest H. Peabody of the Babcock and Wilcox Company states that while tests have been made with coal claiming 80 per cent gross efficiency that such results can only be obtained with the largest units and having the most efficient mechanical stokers. This is an exceptional performance, and is not likely to be attained in daily service. Probably 76 to 78 per cent would be the everyday upper limit. With hand stoking, 75 per cent is about the maximum that can be attained while 65 per cent may be considered as very good average work. Much more excess air is necessary with coal stokers than with oil, and a tremendous excess of air is necessary with hand firing. This air of course pulls down the boiler efficiency.

The excess air ordinarily necessary with fuel oil ranges from 20 to 25 per cent, the best results with hand fired coal requires 50 per cent excess air, while average hand firing will run as high as 80 to 100 per cent excess.

The table may be used in two ways: (1) To find the pounds of oil equal to one pound of coal with a given boiler efficiency, or (2) To find the boiler efficiency when the evaporation per pound of oil is known or when the pounds of water evaporated per pound of coal is known. For example, if the known boiler efficiency is 80 per cent, and 10 pounds of water are evaporated per pound of coal, then 0.6725 pounds of oil will be equal to one pound of coal. The evaporation per pound of oil is 14.87 pounds of water from and at 212° F. It will be noted that the relative value of oil becomes better as the efficiency increases.

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OIL FOR INDUSTRIAL FURNACES

ANNEALING FURNACES FOR STEEL CASTINGS. In a paper read before the Engineer's Club of Philadelphia, James E. Wilson gave some data regarding the use of fuel oil in annealing furnaces. The oil used had a gravity of approximately 32° Baume, a flash point of 212° F., and a calorific value of 140,000 B. T. U. per gallon. Two types of furnace were described ; (1) The car type furnace in which large castings were introduced into the furnace on a wheeled car, and (2) A hand loaded furnace of smaller size for small castings. High pressure compressed air burners were used in the car type furnace, and low pressure burners in the hand loaded furnace, the latter operating at a blower pressure of about 8 ounces per square inch. In his summary, Mr. Wilson says that there is little to choose between the two types of burners in regard to oil consumption, but that the low pressure type effected a saving because no compressor was necessary. The following are the principal dimensions and capacities of the two furnaces:

Furnace Type	Width Feet	Length Feet	Height Feet	Capacity in Lbs.	Oil Req. Gals. p. hr.	Duration of Heat
Car Type Furnace.	5′–0″	12′–0″	3′–6″	14,000	20	10 hours
Hand loaded Type.	4′–0″	8′–0″	2′–0″	3,000	20	8 hours

Thus, in the car type furnace $20 \times 10 = 200$ gals, were required to anneal 14,000 pounds of castings, while in the hand loaded type $20 \times 8 = 160$ gallons were required to anneal 3,000 pounds of castings.

Regulation must be carefully attended to, for if the heat is too intense, the thin portions of the castings will be burned while if the temperature is below the required point the physical structure will not be sufficiently changed. Two burners were used at either end of the furnaces, and these led into combustion chambers which prevented direct contact of the flames on the metal. If the flame is allowed to smoke, the carbon will be absorbed by the metal when heated between 1400-1600° F., and the composition of the castings will be changed making them hard and brittle on the surface. Smoke increases carbon content. The furnace linings were burned out about once a year and were renewed.

COAL EQUIVALENTS IN STEEL WORKING FURNACES. W. N. Best gives the fuel oil requirements of various types of steel furnaces in terms of coal consumption. Thus, if the coal consumption of a certain class of furnace is known a close estimate can be made on the fuel oil consumption. These figures are in terms of gallons of oil per long ton of coal (2,240 pounds):

Flue Welding Furnaces.....58 gallons of oil = 1 ton of coal
Forging Furnaces.....80 gallons of oil = 1 ton of coal
Heat Treating Furnaces (Low Temperature).....80 gallons of oil = 1 ton of coal
Heat Treating Furnaces (High Temperature).....63 gallons of oil = 1 ton of coal
Annealing Ovens.....63 gallons of oil = 1 ton of coal

OIL FOR INDUSTRIAL FURNACES

Continued

OPEN HEARTH STEEL FURNACES. Approximately one barrel of fuel oil will melt one ton of steel in an open hearth furnace with the walls already hot. Oil is much preferable to producer gas for this purpose in the majority of cases for the sulphur content of oil is less than that of the average coal used in steel mills, and the oil is more easily and cheaply handled than a gas producer plant.

Adopting the usual equivalent of 40 gallons oil = 400 pounds of coal = heat required to melt one ton of steel, it will be found that coal introduces 8 pounds of sulphur while the oil introduces only 6 pounds of sulphur, both fuels assumed as carrying 2 percent of sulphur, and having the same heating value. This difference is due to the smaller quantity of oil required. Heavy oils contain more sulphur than the lighter varieties, so that to reduce sulphur to a minimum, light oils are used until the slag forms and then the heavier and more effective oils are turned on to complete the heat. Ordinarily this takes 50% light oil and 50% heavy oil. Not much sulphur is absorbed from any fuel after the slag forms.

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COMPARISON OF OIL AND VARIOUS FUELS

COMPARISONS OF OIL AND COAL. The following table, compiled from data in Bulletin No. 15 of the Kansas City Laboratories, will be a rough guide to the equivalents of oil in terms of various fuels. Exact comparisons of this sort are impossible to make because of the great range in the variations of composition.

EQUIVALENTS

1 Ton of Coal = 3.60 Bbls. of Oil = 24,500 Cu. Ft. of Natural Gas.
1 Gallon of Oil = 13.1 Lbs. Coal = 160 Cu. Ft. Natural Gas.
1 Barrel Oil = 0.278 Ton Coal = 680.6 Cu. Ft. Natural Gas.
1 Pound Oil = 1.75 Lbs. Coal = 21.3 Cu. Ft. Natural Gas.
1 Pound Coal = 0.763 Gallon Oil = 12.2 Cu. Ft. Natural Gas.

These figures are taken from the theoretical heat content as determined by the calorimeter and do not take furnace efficiency, boiler efficiency, etc., into account. The data is based on the following properties of the fuels:

Fuel Oil of 25.7° Baume gravity, 7.5 pounds per gallon, 19,225 B. T. U. per pound, and 144,200 B. T. U. per gallon.
Slack Coal = 11,000 B. T. U. per pound.
Natural Gas = 900 B. T. U. per cubic foot.

COMPARISON OF OIL AND OTHER FUELS. From an article in PETROLEUM MAGAZINE by W. N. Best, the value of oil for various purposes is given in terms of tons of coal and in commercial units of other fuels.

1 Long Ton of Coal in Locomotive..... 180 Gallons of Oil
1 Long Ton of Coal in Average Stationary Boiler... 147 Gallons of Oil
1 Long Ton of Coal in Steamer (Mech. Atomization).. 180 Gallons of Oil
3.25 Barrels of Oil = 5,000 Lbs. Hickory = 4,550 Lbs. White Oak.
6 Gallons Oil = 1,000 Cu. Ft. of Commercial or Water Gas (1,000 B. T. U./Cu. Ft.).
3.5 Gallons Oil = 1,000 Cu. Ft. of Commercial or Water Gas (620 B. T. U./Cu. Ft.).
2.25 Gallons Oil = 1,000 Cu. Ft. Byproduct Coke Oven Gas (440 B. T. U./Cu. Ft.).
0.42 Gallon Oil = 1,000 Cu. Ft. Blast Furnace Gas (90 B. T. U. per Cu. Ft.).

These values are based upon the calorific values only.

COMPARATIVE COSTS OF OIL AND COAL. A handy rule for approximately determining the relative costs of coal and fuel oil is provided by Ernest H. Peabody of the Babcock and Wilcox Company. This is based on the fact that in steam making, one pound of oil is equal to 1.5 pounds of coal, or that 200 U. S. gallons of oil equals one long ton (2,240 pounds) of coal. Conversely, one long ton of coal equals about 4.5 barrels of oil. We can now state the approximate rule for comparative costs.

"When the price of coal in dollars per ton (2,240 pounds) is double the price of oil in cents per U. S. gallon, the cost of fuel for producing a certain boiler capacity will be the same for both fuels. Thus two-cent oil equals $4.00 coal, or four-cent oil equals $8.00 coal."

This rule takes into consideration the probable increased boiler efficiency obtainable with oil, but necessarily makes certain assumptions regarding the heat values of the two fuels, and the weight per gallon of the oil, which may or may not fit some particular case.

COMPARATIVE RATES OF EVAPORATION. Allen F. Brewer gives approximate comparative rates of evaporation of water from and at 212° F.

One pound of fuel oil..... 15.50 pounds of water Evap.
One pound of coal, stoker fired..... 10.00 pounds of water Evap.
One pound of coal, hand fired..... 7.50 pounds of water Evap.

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FUEL OIL TESTS AND COMPARISONS

The data contained in the preceding sheet is combined in the table below, which gives the combined and weighted results of the tests. It will be noted that the test numbers are rearranged so that one watertube and one return tubular boiler is placed under each of the three headings. It was in this sequence that the tests were run.

COMBINED AND WEIGHTED RESULTS—	TESTS 1-4	TESTS 2-5	TESTS 3-6
Heat in oil in B. T. U.	18,564	18,352	18,361
Steam used by burner-pump (%)	3.77%	4.13%	4.29%
Gross Evaporation at 212° F.	14.042	14.077	13.811
Gross Efficiency	73.400	74.440	72.997

These results are not to show what may be expected from a new well designed plant, designed for oil burning, but are to show what may be accomplished with an old altered plant, the boilers and settings of which are old and out of repair. There was probably enough leakage through the brick setting to lower the total efficiency by 5 percent or more.

COMPARISON OF COSTS BY FORMULA. An approximate formula for estimating the comparative prices of coal and fuel oil has been published by the Tidewater Oil Company. This is not exact and will not suit every condition, but it will give a good idea of what may be expected in regard to the relative expenses.

Let A = cost of coal per net ton (Total), including the items in the following example:

Coal cost per net ton on switch	$5.50
Coal cost per net ton for unloading	.50
Coal cost per net ton for lost coal	.30
Cost per net ton delivered to furnace	.50
80% of cost per net ton for firing	.60
80% of cost per net ton handling ashes	.30

A = Total cost of net ton fired and ashed $7.70

B = Factor 1.6, fireroom labor, loss through cleaning fires, etc.

C = Factor 167, base-oil 144,000 B. T. U. per gallon, coal 24,000,000 B. T. U. per ton.

D = Price that can be paid for oil per gallon.

E = Factor 104.

F = Number of gallons to equal coal now used per ton of metal treated.

G = Factor 2000.

H = Pounds of coal now used in treating one ton (2,000 lbs.) of metal.

I = Factor 134—Boilers only—(167 × 0.80).

Then: $D = \frac{A \times B}{C}$ $\quad E = \frac{A}{D}$ $\quad F = \frac{H \times E}{G}$

Boiler formula: $D = \frac{A}{I}$

From A = $7.70 (total cost per ton of coal, and the factor [I] which is equal to 134, we can work out the given problem to obtain the price which can be paid for oil with coal at $7.70 per ton.)

$D = \frac{A}{I} = \frac{\$7.70}{134} = \$0.057$ = price per gallon of oil allowable.

The formula $F = \frac{HE}{G}$ is applicable only to metal working furnaces, not for boilers or power plants.

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WEIGHTS OF VARIOUS MATERIALS

MATERIAL	Specific Gravity	Average Per Cu. Ft Pounds.
BRICK		
Common red	1.8 to 2.00	100
Fire-clay		150
Silica		128
Chrome		175
Magnesia as brick or fused in furnace		160
CEMENT		
Portland		78
FINE GROUND CLAYS, SILICA CEMENT, ETC.		
Fire-clay		85
Silica cement		75
Magnesia cement		127
Chrome cement		135
Grain magnesite (as shipped)		112
COAL AND COKE		
Anthracite	1.4 to 1.7	60
Bituminous	1.2 to 1.5	49
Charcoal		18.5
Coke	1.0 to 1.4	26.3
CONCRETE		
Cement, fine; Stone, Sand	2.2 to 2.4	144
Cement, Slag, etc	1.9 to 2.3	130
EARTH		
Loam, dry, loose		76
Loam, packed		95
Loam, soft, loose mud		108
Loam, dense mud		125
GLASS		
Common window	2.4 to 2.6	157
Plate	2.45 to 2.72	172
Crystal	2.90 to 3.00	184
Floor or skylight		158
GRAIN		
Corn		45
Oats		24
Wheat		48
LIME		
Quick, loose lumps		53
Quick, fine		75
Stone, large rocks		168
Stone, irregular lumps		96
MASONRY		
Granite or limestone		165
Mortar, rubble		154
Dry		138
Sandstone, dressed		144
METALS		
Aluminum		166
Brass, cast, rolled	7.7	534
Bronze, 7.9 to 14% Sn	7.4 to 8.9	509
Copper, cast		537
Copper, rolled or wire		555
Iron cast, pig	7.2	450
Iron, wrought	7.6 to 7.9	485

WEIGHTS OF VARIOUS MATERIALS

MATERIAL	Specific Gravity	Average Per Cu. Ft. Pounds
METALS—Continued.		
Lead, cast		708
Lead, Ore—Galena	7.3 to 7.6	465
Steel, cast		490
Steel, rolled		495
Tin, cast		459
Zinc, cast		438
OILS		
Engine		55
Crude		48
Petroleum		55
Gasoline		43
ROCK		
Dolomite	2.9	181
Granite		165
Gypsum		143
Sandstone		144
Pumice stone		57
Quartz		165
Salt, coarse		45
Salt, fine		49
Shales		162
Slate, American		175
SAND		
Dry and loose		100
Dry and packed		110
Wet and packed		130
Gravel packed		118
WATER		
Water as ice		58.7
Water at 32 degrees Fahrenheit		62.4
Water at 212 degrees Fahrenheit		59.6
WOODS, DRY		
Ash	0.62 to 0.65	40
Beech		43
Birch		45
Cedar, American	0.32 to 0.38	22
Chestnut	0.66	41
Cypress	0.48	30
Fir, Douglas	0.51	32
Hemlock	0.42 to 0.52	29
Hickory	0.74 to 0.84	49
Ironwood		114
Mahogany		35 to 53
Maple, hard	0.68	43
Oak, live	0.95	59
Oak, white	0.74	46
Pine, white		25
Pine, yellow northern		34
Pine, yellow southern		45
Spruce		25
Walnut		35

CIRCUMFERENCES AND AREAS OF CIRCLES
From 1-64 to 100

Diam.	Circum.	Area	Diam.	Circum.	Area
1/64	.04909	.000192	4	12.5664	12.5664
1/32	.09818	.000767	4 1/8	12.9591	13.3641
1/16	.19635	.003068	4 1/4	13.3518	14.1863
3/32	.3927	.012272	4 3/8	13.7445	15.033
3/16	.589	.027612	4 1/2	14.1372	15.9043
1/4	.7854	.049087	4 5/8	14.5299	16.8002
5/16	.98175	.076699	4 3/4	14.9226	17.7206
3/8	1.1781	.110447	4 7/8	15.3153	18.6555
7/16	1.37445	.15033			
1/2	1.5708	.19635	5	15.708	19.635
9/16	1.76715	.248505	5 1/8	16.1007	20.629
5/8	1.9635	.306796	5 1/4	16.4934	21.6476
11/16	2.15985	.371224	5 3/8	16.8861	22.6907
3/4	2.3562	.441787	5 1/2	17.2788	23.7583
13/16	2.55255	.518487	5 5/8	17.6715	24.8505
7/8	2.7489	.601322	5 3/4	18.0642	25.9673
15/16	2.94525	.690292	5 7/8	18.4569	27.1086
1	3.1416	.7854	6	18.8496	28.2744
1 1/8	3.5343	.99402	6 1/8	19.2423	29.4648
1 1/4	3.927	1.2272	6 1/4	19.635	30.6797
1 3/8	4.3197	1.4849	6 3/8	20.0277	31.9191
1 1/2	4.7124	1.7671	6 1/2	20.4204	33.1831
1 5/8	5.1051	2.0739	6 5/8	20.8131	34.4717
1 3/4	5.4978	2.4053	6 3/4	21.2058	35.7848
1 7/8	5.8905	2.7612	6 7/8	21.5935	37.1224
2	6.2832	3.1416	7	21.9912	38.4846
2 1/8	6.6759	3.5466	7 1/8	22.3839	39.8713
2 1/4	7.0686	3.9761	7 1/4	22.7766	41.2826
2 3/8	7.4613	4.4301	7 3/8	23.1693	42.7184
2 1/2	7.854	4.9087	7 1/2	23.562	44.1787
2 5/8	8.2467	5.4119	7 5/8	23.9547	45.6636
2 3/4	8.6394	5.9396	7 3/4	24.3474	47.1731
2 7/8	9.0321	6.4918	7 7/8	24.7401	48.7071
3	9.4248	7.0686	8	25.1328	50.2656
3 1/8	9.8175	7.6699	8 1/8	25.5255	51.8487
3 1/4	10.2102	8.2958	8 1/4	25.9182	53.4563
3 3/8	10.6029	8.9462	8 3/8	26.3109	55.0884
3 1/2	10.9956	9.6211	8 1/2	26.7036	56.7451
3 5/8	11.3883	10.3206	8 5/8	27.0963	58.4264
3 3/4	11.781	11.0447	8 3/4	27.489	60.1322
3 7/8	12.1737	11.7933	8 7/8	27.8817	61.8625

CIRCUMFERENCES AND AREAS OF CIRCLES

Continued

Diam.	Circum.	Area	Diam.	Circum.	Area
9	28.2744	63.6174	15	47.124	176.715
9 1/8	28.6671	65.3968	15 1/8	47.5167	179.673
9 1/4	29.0598	67.2008	15 1/4	47.9094	182.655
9 3/8	29.4525	69.0293	15 3/8	48.3021	185.661
9 1/2	29.8452	70.8823	15 1/2	48.6948	188.692
9 5/8	30.2379	72.7599	15 5/8	49.0875	191.748
9 3/4	30.6306	74.6621	15 3/4	49.4802	194.828
9 7/8	31.0233	76.5888	15 7/8	49.8729	197.933
10	31.416	78.54	16	50.2656	201.062
10 1/8	31.8087	80.5158	16 1/8	50.6583	204.216
10 1/4	32.2014	82.5161	16 1/4	51.051	207.395
10 3/8	32.5941	84.5409	16 3/8	51.4437	210.598
10 1/2	32.9868	86.5903	16 1/2	51.8364	213.825
10 5/8	33.3795	88.6643	16 5/8	52.2291	217.077
10 3/4	33.7722	90.7628	16 3/4	52.6218	220.354
10 7/8	34.1649	92.8858	16 7/8	53.0145	223.655
11	34.5576	95.0334	17	53.4072	226.981
11 1/8	34.9503	97.2055	17 1/8	53.7999	230.331
11 1/4	35.343	99.4022	17 1/4	54.1926	233.906
11 3/8	35.7357	101.6234	17 3/8	54.5853	237.105
11 1/2	36.1284	103.8691	17 1/2	54.978	240.529
11 5/8	36.5211	106.1394	17 5/8	55.3707	243.977
11 3/4	36.9138	108.4343	17 3/4	55.7634	247.45
11 7/8	37.3065	110.7537	17 7/8	56.1561	250.948
12	37.6992	113.098	18	56.5488	254.47
12 1/8	38.0919	115.466	18 1/8	56.9415	258.016
12 1/4	38.4846	117.859	18 1/4	57.3342	261.587
12 3/8	38.8773	120.277	18 3/8	57.7269	265.183
12 1/2	39.27	122.719	18 1/2	58.1196	268.803
12 5/8	39.6627	125.185	18 5/8	58.5123	272.448
12 3/4	40.0554	127.677	18 3/4	58.905	276.117
12 7/8	40.4481	130.192	18 7/8	59.2977	279.811
13	40.8408	132.733	19	59.6904	283.529
13 1/8	41.2335	135.297	19 1/8	60.0831	287.272
13 1/4	41.6262	137.887	19 1/4	60.4758	291.04
13 3/8	42.0189	140.501	19 3/8	60.8685	294.832
13 1/2	42.4116	143.139	19 1/2	61.2612	298.648
13 5/8	42.8043	145.802	19 5/8	61.6539	302.489
13 3/4	43.197	148.49	19 3/4	62.0466	306.355
13 7/8	43.5897	151.202	19 7/8	62.4393	310.245
14	43.9824	153.938	20	62.832	314.16
14 1/8	44.3751	156.7	20 1/8	63.2247	318.099
14 1/4	44.7678	159.485	20 1/4	63.6174	322.063
14 3/8	45.1605	162.296	20 3/8	64.0101	326.051
14 1/2	45.5532	165.13	20 1/2	64.4028	330.064
14 5/8	45.9459	167.99	20 5/8	64.7955	334.102
14 3/4	46.3386	170.874	20 3/4	65.1882	338.164
14 7/8	46.7313	173.782	20 7/8	65.5809	342.25

CIRCUMFERENCES AND AREAS OF CIRCLES

Continued

Diam.	Circum.	Area	Diam.	Circum.	Area
21	65.9736	346.361	27	84.8232	572.557
21 1/8	66.3663	350.497	27 1/8	85.2159	577.87
21 1/4	66.759	354.657	27 1/4	85.6086	583.209
21 3/8	67.1517	358.842	27 3/8	86.0013	588.571
21 1/2	67.5444	363.051	27 1/2	86.394	593.959
21 5/8	67.9379	367.285	27 5/8	86.7867	599.371
21 3/4	68.3298	371.543	27 3/4	87.1794	604.807
21 7/8	68.7225	375.826	27 7/8	87.5729	610.268
22	69.1152	380.134	28	87.9648	615.754
22 1/8	69.5079	384.466	28 1/8	88.3575	621.264
22 1/4	69.9006	388.822	28 1/4	88.7502	626.798
22 3/8	70.2933	393.203	28 3/8	89.1429	632.357
22 1/2	70.686	397.609	28 1/2	89.5356	637.941
22 5/8	71.0787	402.038	28 5/8	89.9283	643.549
22 3/4	71.4714	406.494	28 3/4	90.321	649.182
22 7/8	71.8641	410.973	28 7/8	90.7137	654.84
23	72.2568	415.477	29	91.1064	660.521
23 1/8	72.6495	420.004	29 1/8	91.4991	666.228
23 1/4	73.0422	424.558	29 1/4	91.8918	671.959
23 3/8	73.4349	429.135	29 3/8	92.2845	677.714
23 1/2	73.8276	433.737	29 1/2	92.6772	683.494
23 5/8	74.2203	438.364	29 5/8	93.0699	689.299
23 3/4	74.613	443.015	29 3/4	93.4626	695.128
23 7/8	75.0057	447.69	29 7/8	93.8553	700.982
24	75.3984	452.39	30	94.248	706.86
24 1/8	75.7911	457.115	30 1/8	94.6407	712.763
24 1/4	76.1838	461.864	30 1/4	95.0334	718.69
24 3/8	76.5765	466.638	30 3/8	95.4261	724.642
24 1/2	76.9692	471.436	30 1/2	95.8188	730.618
24 5/8	77.3619	476.259	30 5/8	96.2115	736.619
24 3/4	77.7546	481.107	30 3/4	96.6042	742.645
24 7/8	78.1473	485.979	30 7/8	96.9969	748.695
25	78.54	490.875	31	97.3896	754.769
25 1/8	78.9327	495.796	31 1/8	97.7823	760.869
25 1/4	79.9254	500.742	31 1/4	98.175	766.992
25 3/8	79.7181	505.712	31 3/8	98.5677	773.14
25 1/2	80.1108	510.706	31 1/2	98.9604	779.313
25 5/8	80.5035	515.726	31 5/8	99.3531	785.51
25 3/4	80.8962	520.769	31 3/4	99.7458	791.732
25 7/8	81.4889	525.838	31 7/8	100.1385	797.979
26	81.6816	530.93	32	100.5312	804.25
26 1/8	82.0743	536.048	32 1/8	100.9239	810.545
26 1/4	82.476	541.19	32 1/4	101.3166	816.865
26 3/8	82.8597	546.356	32 3/8	101.7093	823.21
26 1/2	83.2524	551.547	32 1/2	102.102	829.579
26 5/8	83.6451	556.763	32 5/8	102.4947	835.972
26 3/4	84.0378	562.003	32 3/4	102.8874	842.391
26 7/8	84.4305	567.267	32 7/8	103.2801	848.833

CIRCUMFERENCES AND AREAS OF CIRCLES

Continued

Diam.	Circum.	Area	Diam.	Circum.	Area
33	103.673	855.301	39	122.522	1194.593
33 1/8	104.065	861.792	39 1/8	122.915	1202.263
33 1/4	104.458	868.309	39 1/4	123.308	1209.958
33 3/8	104.851	874.85	39 3/8	123.7	1217.677
33 1/2	105.344	881.415	39 1/2	124.093	1225.42
33 5/8	105.636	888.005	39 5/8	124.486	1233.188
33 3/4	106.029	894.62	39 3/4	124.879	1240.981
33 7/8	106.422	901.259	39 7/8	125.271	1248.798
34	106.814	907.922	40	125.664	1256.64
34 1/8	107.207	914.611	40 1/8	126.057	1264.51
34 1/4	107.6	921.323	40 1/4	126.449	1272.4
34 3/8	107.992	928.061	40 3/8	126.842	1280.31
34 1/2	108.385	934.822	40 1/2	127.235	1288.25
34 5/8	108.778	941.609	40 5/8	127.627	1296.22
34 3/4	109.171	948.42	40 3/4	128.02	1304.21
34 7/8	109.563	955.255	40 7/8	128.413	1312.22
35	109.956	962.115	41	128.806	1320.26
35 1/8	110.349	969.	41 1/8	129.198	1328.32
35 1/4	110.741	975.909	41 1/4	129.591	1336.41
35 3/8	111.134	982.842	41 3/8	129.984	1344.52
35 1/2	111.527	989.8	41 1/2	130.376	1352.66
35 5/8	111.919	996.783	41 5/8	130.769	1360.82
35 3/4	112.312	1003.79	41 3/4	131.162	1369.
35 7/8	112.705	1010.822	41 7/8	131.554	1377.21
36	113.098	1017.878	42	131.947	1385.45
36 1/8	113.49	1024.96	42 1/8	132.34	1393.7
36 1/4	113.883	1032.065	42 1/4	132.733	1401.99
36 3/8	114.276	1039.195	42 3/8	133.125	1410.3
36 1/2	114.668	1046.349	42 1/2	133.518	1418.63
36 5/8	115.061	1053.528	42 5/8	133.911	1426.99
36 3/4	115.454	1060.732	42 3/4	134.303	1435.37
36 7/8	115.846	1067.96	42 7/8	134.696	1443.77
37	116.239	1075.213	43	135.089	1452.2
37 1/8	116.632	1082.49	43 1/8	135.481	1460.66
37 1/4	117.025	1089.792	43 1/4	135.874	1469.14
37 3/8	117.417	1097.118	43 3/8	136.267	1477.64
37 1/2	117.81	1104.469	43 1/2	136.66	1486.17
37 5/8	118.203	1111.844	43 5/8	137.052	1494.73
37 3/4	118.595	1119.244	43 3/4	137.445	1503.3
37 7/8	118.988	1126.669	43 7/8	137.838	1511.91
38	119.381	1134.118	44	138.23	1520.53
38 1/8	119.773	1141.591	44 1/8	138.623	1529.19
38 1/4	120.166	1149.089	44 1/4	139.016	1537.86
38 3/8	120.559	1156.612	44 3/8	139.408	1546.56
38 1/2	120.952	1164.159	44 1/2	139.801	1555.29
38 5/8	121.344	1171.731	44 5/8	140.194	1564.04
38 3/4	121.737	1179.327	44 3/4	140.587	1572.81
38 7/8	122.13	1186.948	44 7/8	140.979	1581.61

CIRCUMFERENCES AND AREAS OF CIRCLES

Continued

Diam.	Circum.	Area	Diam.	Circum.	Area
45	141.372	1590.43	51	160.22	2042.82
45 1/8	141.765	1599.28	52	163.36	2123.71
45 1/4	142.157	1608.16	53	166.50	2206.18
45 3/8	142.55	1617.05	54	169.65	2290.21
45 1/2	142.943	1625.97	55	172.79	2375.82
45 5/8	143.335	1634.92	56	175.93	2463.01
45 3/4	143.728	1643.89	57	179.07	2551.75
45 7/8	144.121	1652.89	58	182.21	2642.08
			59	185.35	2733.97
			60	188.50	2827.43
46	144.514	1661.91	61	191.64	2922.46
46 1/8	144.906	1670.95	62	194.78	3019.07
46 1/4	145.299	1680.02	63	197.92	3117.24
46 3/8	145.692	1689.11	64	201.06	3216.99
46 1/2	146.084	1698.23	65	204.20	3318.30
46 5/8	146.477	1707.37	66	207.35	3421.18
46 3/4	146.87	1716.54	67	210.49	3525.65
46 7/8	147.262	1725.73	68	213.63	3631.68
			69	216.77	3739.28
			70	219.91	3848.45
47	147.655	1734.95			
47 1/8	148.048	1744.19	71	223.05	3959.19
47 1/4	148.441	1753.45	72	226.19	4071.50
47 3/8	148.833	1762.74	73	229.34	4185.38
47 1/2	149.226	1772.06	74	232.48	4300.84
47 5/8	149.619	1781.4	75	235.62	4417.86
47 3/4	150.011	1790.76	76	238.76	4536.45
47 7/8	150.404	1800.15	77	241.90	4656.62
			78	245.04	4778.36
			79	248.19	4901.66
			80	251.33	5026.54
48	150.797	1809.56			
48 1/8	151.189	1819.	81	254.47	5153.00
48 1/4	151.582	1828.46	82	257.61	5281.01
48 3/8	151.975	1837.95	83	260.75	5410.59
48 1/2	152.368	1847.46	84	263.89	5541.77
48 5/8	152.76	1856.99	85	267.04	5674.50
48 3/4	153.153	1866.55	86	270.18	5808.80
48 7/8	153.546	1876.14	87	273.32	5944.67
			88	276.46	6082.11
			89	279.60	6221.13
			90	282.74	6361.72
49	153.938	1885.75			
49 1/8	154.331	1895.38	91	285.88	6503.87
49 1/4	154.724	1905.04	92	289.03	6647.61
49 3/8	155.116	1914.72	93	292.17	6792.90
49 1/2	155.509	1924.43	94	295.31	6939.78
49 5/8	155.902	1934.16	95	298.45	7088.21
49 3/4	156.295	1943.91	96	301.59	7238.23
49 7/8	156.687	1953.69	97	304.73	7389.81
			98	307.88	7542.96
			99	311.02	7697.68
50	157.08	1963.5	100	314.16	7853.97

DECIMALS OF AN INCH FOR EACH 1-64th

1-64	.015625	33-64	.515625
1-32	.03125	17-32	.53125
3-64	.046875	35-64	.546875
1-16	.0625	9-16	.5625
5-64	.078125	37-64	.578125
3-32	.09375	19-32	.59375
7-64	.109375	39-64	.609375
1-8	.125	5-8	.625
9-64	.140625	41-64	.640625
5-32	.15625	21-32	.65625
11-64	.171875	43-64	.671875
3-16	.1875	11-16	.6875
13-64	.203125	45-64	.703125
7-32	.21875	23-32	.71875
15-64	.234375	47-64	.734375
1-4	.250	3-4	.75
17-64	.265625	49-64	.765625
9-32	.28125	25-32	.78125
19-64	.296875	51-64	.796875
5-16	.3125	13-16	.8125
21-64	.328125	53-64	.828125
11-32	.34375	27-32	.84375
23-64	.359375	55-64	.859375
3-8	.375	7-8	.875
25-64	.390625	57-64	.890625
13-32	.40625	29-32	.90625
27-64	.421875	59-64	.921875
7-16	.4375	15-16	.9375
29-64	.453125	61-64	.953125
15-32	.46875	31-32	.96875
31-64	.484375	63-64	.984375
1-2	.500	1	1.

METRIC WEIGHTS AND MEASURES

METRIC WEIGHTS

Milligram (.001 gram)	0.0154	grain
Centigram (.01 gram)	0.1543	grain
Decigram (.1 gram)	1.5432	grains
Gram	15.4324	grains
Decagram (10 grams)	0.3527	oz. avoir.
Hectogram (100 grams)	3.5274	oz. avoir.
Kilogram (1000 grams)	2.2046	lbs. avoir.
Myriagram (10,000 grams)	22.02462	lbs. avoir.
Quintal (100 kilos)	220.4622	lbs. avoir.
Millier or Ton (1000 kilos)	2,204.6223	lbs. avoir.

METRIC DRY MEASURES

Milliliter (.001 liter)	0.061	cu. in.
Centiliter (.01 liter)	0.6103	cu. in.
Deciliter (.1 liter)	6.1027	cu. in.
Liter	0.9081	quart
Decaliter (10 liters)	9.0808	quarts
Hectoliter (100 liters)	2.8377	bushels
Kiloliter (1000 liters)	1.3079	cu. yds.

METRIC LIQUID MEASURES

Milliliter (.001 liter)	0.0338	fluid oz.
Centiliter (.01 liter)	0.3381	fluid oz.
Deciliter (.1 liter)	0.8452	gill
Liter	1.0567	quarts
Decaliter (10 liters)	2.6417	gallons
Hectoliter (100 liters)	26.4170	gallons
Kiloliter (1000 liters)	264.1705	gallons

METRIC WEIGHTS AND MEASURES
Continued

METRIC MEASURES OF LENGTH

Millimeter (.001 meter)	0.03937	inch
Centimeter (.01 meter)	0.3937	inch
Decimeter (.1 meter)	3.937	inches
Meter	39.37	inches
Decameter (10 meters)	32.8083	feet
Hectometer (100 meters)	328.083	feet
Kilometer (1000 meters)	3280.83	feet
Kilometer (1000 meters)	0.62137	mile
Myriameter (10,000 meters)	6.2137	miles

METRIC SURFACE MEASURES

Centare (1 sq. meter)	1,550	sq. in.
Are (100 sq. meters)	119.6	sq. yds.
Hectare (10,000 sq. meters)	2.471	acres

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